INVESTIGATION OF PHYSICO-MECHANICAL & DIELECTRICAL PROPERTIES OF BIO-WASTE REINFORCED POLYMER COMPOSITES

Thesis submitted in partial fulfillment of
the requirements for the degree of

Master of Technology

in

METALLURGICAL AND MATERIALS ENGINEERING

By

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DEDICATED TO

MY FATHER

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CERTIFICATE

This is to certify that, the work in the report entitled **"Investigation on Physico-Mechanical & Electrical properties of Bio-waste Reinforced Polymer Composites"** by **Mr Harinath Aireddy,** in partial fulfilment of Master of Technology degree in **METALLURGICAL & MATERIALS ENGINEERING** at the National Institute of Technology, Rourkela(Deemed University); is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/institute for award of any Degree or Diploma.

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Date: **Harinath Aireddy**

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ABSTRACT

In recent years, The incorporation of natural fibers as reinforcing agent in polymer composite has gained increasing interest which enhances optimal utilization of natural resources and particularly of renewable resources. Natural fibers have proven to be suitable reinforcement materials for composite; thanks to a combination of good mechanical, high electrical (insulating), impact resistance, good thermal and acoustic insulating properties and with environmental advantages such as renewability and bio-degradability, comparable to synthetic fiber reinforced polymer composites. Hence, for these reasons it has not been surprising that the use of natural materials in the production of composites has gained significant importance both in technical applications such as in automotive industry, as well as in the electronics industry for its dielectric and insulating properties in the use of capacitors, microelectronic components (such as transistors and ICs), and safe insulators for low to moderate voltages (hundreds of volts). In this present research work, we have investigated the dielectrical, mechanical, erosive and abrasive wear behavior of bio-waste (coir dust) reinforced polymer composite.

Dielectric analysis was performed on low density Bio-Waste Coir dust reinforced polymer composites. The dielectric parameters(relative permittivity ε', dielectric loss ε"), dielectric conductivity σ and resistivity ρ of pure epoxy resin and composites with different weight percent of coir dust were obtained in a frequency range of 100 Hz-1 MHz, and temperature range of 30-150° C. The experimental results shows that ε', ε", and σ are increased and ρ is decreased with the addition of coir dust in epoxy resin, and also it observed that the dielectrical properties of the composites showed a strong dependence on testing frequency and temperature. The ε', and ε" increases with increasing temperature because of greater movement of the dipole molecular chains and decreases with increasing frequency due to the orientation polarization. The conductivity of the composite is increased, and the resistivity of composite is decreased with increasing frequency

Experiments are conducted to investigate the erosive and abrasive wear behavior of coir dust filled epoxy resin matrix composites. The effect of coir dust concentration , different impingement angles(30°,45°,60°,75°,and 90°),and various impact velocities(34,48,60,78,and 92m/sec) on the erosion rate of composite has been analyzed .The erodent used here is dry silica sand having the size range 200-600μm. However, it is found that the composite shows brittle type failure and maximum erosion rate is observed at 90° impingement angle. Erosion wear rate is decreased with increasing the coir dust amount. The abrasive wear property of the composite is examined on a pin-on-disc machine against 400μm grit size abrasive paper with test speed of 0.540 m/sec and at normal loads 5,10,15,20, and 25N. The effect of coir dust concentration and sliding distance on the weight loss of composites has been analyzed. Abrasive wear resistance decreases with increase in normal load and increases with increasing fiber content. Further, the erodent and abrasive worn surface morphology is examined by using scanning electron microscope (SEM), and possible wear mechanisms are discussed. The hardness and flexural strength of the composite are also evaluated.

In order to improve the strength and to reduce the sensitivity to environmental influences, the interfacial adhesion between the natural fiber and the matrix material was improved by chemical treatment of the coir dust. Dielectric constant of treated coir dust composite was lower than of that of untreated coir dust composite, i.e. the dielectric strength of the composite increases and the increased dielectric strength makes these composites quite suitable for use as insulators.

Key Words: composite materials, orientation polarization, dielectric loss, conductivity, resistivity, dielectric relaxation, epoxy resin, erosion wear, abrasive wear, impingement angle, SEM.

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INTRODUCTION

- Motivation and Background
- Objectives of Study
- Scope of Study

CHAPTER 1

INTRODUCTION

1.1 MOTIVATION AND BACK GROUND

A composite material is a combination of two or more materials of which performance characteristics exceed those which are not achievable from its individual components **[1]**. The purpose of composites is to allow the new material to have strengths from both materials, often times covering the original materials' weaknesses. Composites are different from alloys because alloys are combined in such a way that it is impossible to tell one particle, element, or substance from the other.

The individual materials that make up composites are called *constituents.* Most composites have two constituent materials: a binder or *matrix*, and reinforcement. The reinforcement is usually much stronger and stiffer than the matrix, and gives the composite its good properties. The matrix holds the reinforcements in an orderly pattern. When the reinforcements are discontinuous, the matrix also helps to transfer load among the reinforcements. Some common composite materials include concrete, fiber glass, mud bricks, and natural composites such as rock and wood.

1.1.1 Types of reinforcement phase:

Reinforcements basically come in three forms:

Particulate,

Discontinuous fiber, and

Continuous fiber.

A particle has roughly equal dimensions in all directions, though it doesn't have to be spherical. Gravel, micro balloons, and resin powder are examples of particulate reinforcements.

Reinforcements become fibers when one dimension becomes long compared to others. Discontinuous reinforcements (chopped fibers, milled fibers, or whiskers) vary in length from a few millimetres to a few centimetres. Most fibers are only a few microns in diameter, so it doesn't take much length to make the transition from particle to fiber.

With either particles or short fibers, the matrix must transfer the load at very short intervals. Thus, the composite properties cannot come close to the reinforcement properties. With continuous fibers, however, there are few if any breaks in the reinforcements. Composite properties are much higher, and continuous fibers are therefore used in most high performance components, be they aerospace structures or sporting goods.

1.1.2 Types of Matrix phase:

Matrix phase basically come in three forms:

Metal Matrix

Ceramic Matrix

Polymer Matrix

In general, metals and polymers are used as matrix materials because some ductility is desirable; for ceramic-matrix composites, the reinforcing component is added to improve toughness.

In polymer composites , fibrous materials e.g. ,synthetic or natural, serve either as filler or as reinforcement by giving strength ,stiffness structure and influenced the insulating and dielectric properties, while polymer matrix serves as the adhesive to hold the fibers in place.

Natural fibers have been extensively used as reinforcements into polymer matrices as an alternate to the commonly used synthetic fibers like carbon, glass or aramid because of their low-density good mechanical and dielectric properties, abundant availability and bio-degradability **[2-4]**.

Generally the properties of composite material are strongly influenced by the properties of its constituents. Various factors that affect the properties of composites are,

- Fiber dispersion
- Orientation and geometry(aspect ratio) of the fibers
- The volume fraction of the fiber and Quality of inter face between the polymer matrices and reinforcing fibers **[5]**.

To obtain good performance composite need good dispersion of the fiber in the polymer matrix is required. Lack of dispersion can results in agglomeration of fibers, which lead to the composite properties falling short of their reinforcing potential. Polymer matrix in PMCs can be either a thermoplastic or a thermosetting.

- Thermosetting –Epoxy resin, polyester
- Thermo plastics— Amorphous-polysalphones ,

  Semi crystalline-PEEK (poly ether ketone)

  Crystalline – Nylon

Some of the advantages and disadvantages of these polymer matrices are summarized in bellow table 1.1 **[6]**.

Property	**Thermoplastics**	**Thermo settings**
Processing	High	Low to moderate high
Fabrication cost	Low	High
Environmental durability	Unknown	Good
Solvent resistance	Poor to good	Excellent
Damage tolerance	Fair to good	Poor to excellent
Formulation	Simple	Complex
Fiber impregnation	Difficult	Easy

Table 1.1: Advantages and disadvantages of the polymer matrices.

1.1.3 Fabrication of the polymer composites:

There are many commercial processes for the manufacture of PMCs. These may be sub divided in a variety of ways, but broadly speaking there are three main approaches to the manufacture of fiber –reinforced thermosetting resins and two distinct production methods for thermo plastic composites.

Fabrication methods for Thermo settings are

- Liquid resin impregnation routs
- Pressurized consolidation of resin pre-pregs
- Consolidation of resin molding compounds

Fabrication methods for Thermo plastics

- Injection moulding
- Hot press moulding

1.1.4 Advantages of composites:

Combination of high strength and stiffness with low density
(Reduced in-service cost)

High corrosion resistance
(Reduced maintenance cost)

Flexibility in design and production
(Parts integration, shape flexibility)

Improved fatigue behaviour
(Reduce in-service and maintenance cost)

Specific properties
(Ex. Zero thermal expansion, radar transparency)

1.1.5 Disadvantages of composites:

High constituent materials cost
(Increased production cost)

Anisotropic behaviour
(Complex design calculations)

New joining and repair technologies
(Increased maintenance cost)

Complex damage development during service
(Increased maintenance cost)

Difficult to recycle
(Increased end-of-life cost)

1.1.6 Most used reinforcement (glass fibre):

Most used reinforcement in Composites is the glass fibre it doesn't give best solution to environmental problems, it required massive amount of energy to produce, and contains abrasiveness.

1.1.7 Alternatives for glass fibre:

Instead of glass fibre we can also use natural fibres to prepare the composites. A number of researches have been reported on natural fiber reinforced thermosettings and thermoplastics composites, which have successfully proven their applicability in different kind of fields .Thermoplastics and thermo settings such as polyethylene**[7-9]** ,polypropylene**[10-12]**, polyvinyl chloride **[13-14]**,polystyrene**[15]** , polylatice acid**[16-17]**, and epoxy resin **[18]** have been compounded with natural and bio fibers such as wood, kenaf , rice husk, hemp, cotton, chicken feather, and coir dust e.t.c. shown in the following figure 1.1.











FLAX
HEMP
KENAF
JUTE
HENEQUEN
COIR
WOOD
CORN
GRASS

Figure 1.1: Various Natural fibers.

1.1.8 Advantages of natural fibers:

- Biodegradable
- Renewable
- Less density
- Low cost
- Can be thermally recycled (posses a good calorific value)
- Give less problem concerning health and safety of workers
- Less abrasive
- Good specific properties
- Good dielectric, thermal and acoustic properties

1.1.9 Disadvantages of natural fibers:

- Moisture Adsorption
- Swelling leads to micro-cracking
- Restricted processing temperature
- Low strength
- Smell of natural fibres when process at high temperature

1.1.10 Applications of the natural fiber composites:

Natural fibers are replacing synthetic fibers as reinforcement in various matrices. The composites so prepared can effectively be used as substitute for wood and also in various other technical fields, e.g. building parts, infrastructure, marine, transportation, and industrial /consumer. Figures 1.2 and 1.3 shows various applications of the natural fiber composites.

Building Products

Decking, Window/Door, Fencing, Decorative Trim, Railings

Infrastructure

Boardwalks, Bridge, Guardrails

Marine

Small fishing boats

Transportation

Interior Panels, Shelves, Ducting, Truck Floor, Head liners

Industrial/Consumer

Pallets, Playground, Benches/Tables, Floorings, Trash

Figure 1.2 and 1.3 shows the some constructive and automotive parts made by the natural fiber composites.

Siding and soffit products

Marina

Pool

Figure 1.2: Construction applications

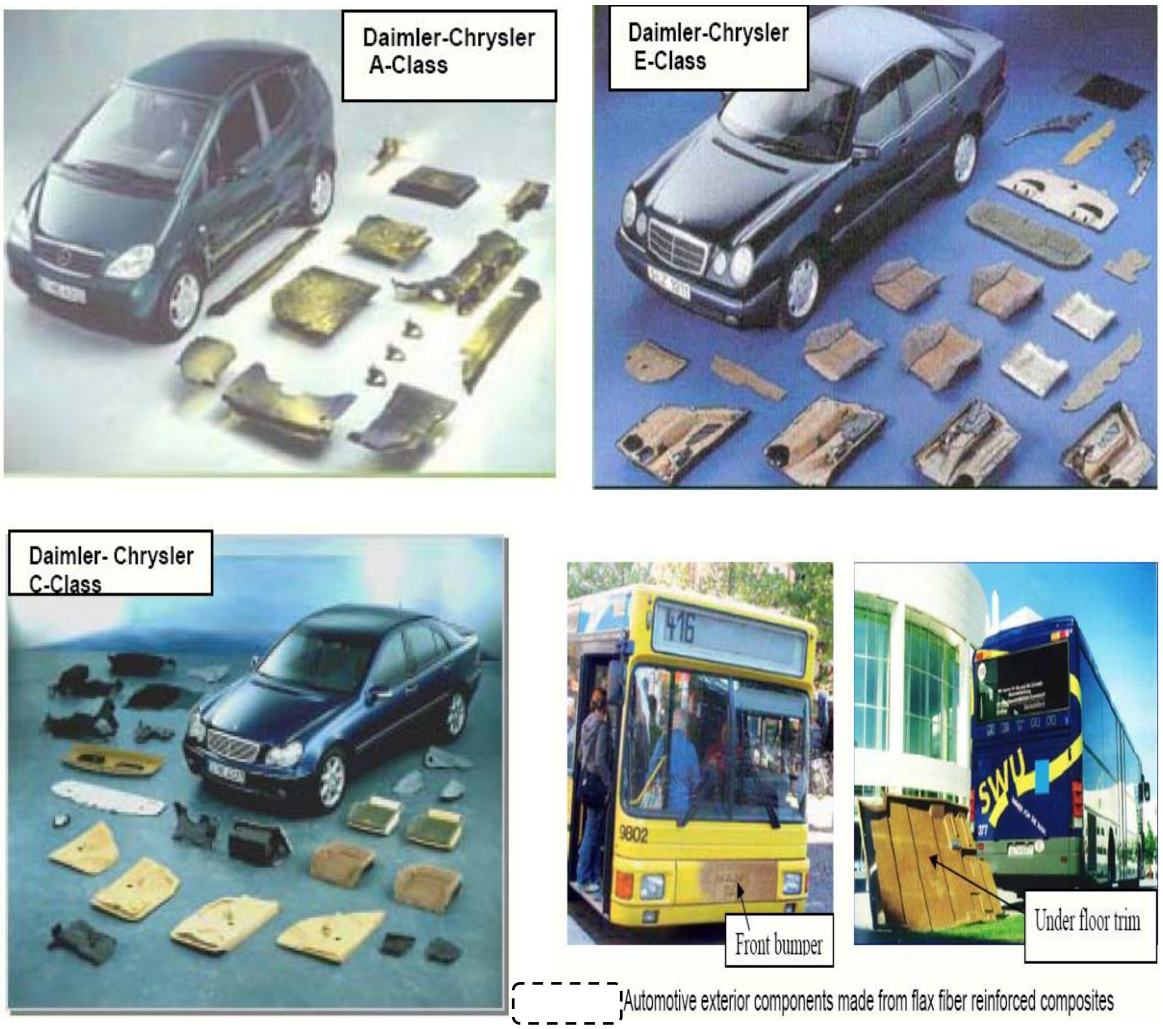


Figure 1.3: Automotive parts made by natural fiber composites

1.2 OBJECTIVES OF STUDY

- Utilization of bio-waste coir dust material in the production of composites.
- Study the characteristics of bio-waste reinforced polymer composites in terms physical parameters essential for their acceptance as marketable products.
- Improvement of the interfacial adhesion between the natural fiber and the matrix material in order to improve the strength and to reduce the sensitivity to environmental influences.
- Comparative effects of epoxy resin: coir dust ratios on material characteristics of resulted polymeric matrix composite.

1.3 SCOPE OF STUDY

Scope this project work was focused on the following steps

1. Preparation of bio waste reinforced polymer composites involving the following stages:
    a. The processing of coconut husks for coir fiber
    b. Subsequent mixing of bio-waste coir dust with epoxy resin
    c. Hand lay-up method.
2. Coir dust loading at the rate of 0, 10, 20, 40, and 60% by weight of total sample using coir dust particle having 200 μm sizes.
3. Determination and Evaluation of Physico-Mechanical properties through Archimedes principle, flexural test (ASTM), and hardness test (ASTM).

4. Investigation of the wear properties such as abrasive and erosive.
5. Characterise the fracture surface and worn surface morphology of the composites by using Scanning Electron Microscopy.
6. Study the dielectrical and electrical properties such as dielectrical constant, dielectrical loss, A.C conductivity, and A.C. resistivity as a function of testing temperature and frequency of applied electric field.
7. Detect various characteristic functional groups in molecules of composites by FTIR spectroscopy analysis.
8. Study the effect of chemical treatment on physic-mechanical and dielectrical properties of the composites.

Chapter 2

LITERATURE SURVEY

- Preamble
- Natural fiber reinforced composites
- Mechanical properties of Natural fibers
- Wear properties of composites
- Stages of wear
- Types of wear
- Dielectrics
- Dielectric mechanisms
- Dielectric nature of the polymer composites
- Chemical Treatment of Natural fibers

CHAPTER 2

LITERATURE SURVEY

2.1 PREAMBLE

This chapter deals with the literature survey of the broad topic of interest namely the utilization of natural fibers as reinforcing agents in the preparation of composites for dielectrical and tribological applications. This treatise embraces coir dust reinforced epoxy composite and their characteristics. The wear resistance performances of these natural fiber composites have been reviewed critically along with the corresponding failure mechanisms. It also presents a review of the efforts that have been directed worldwide towards management issues of utilization, storage and disposal of coir dust, which is the material of interest in this work.

2.2 NATURAL FIBER REINFORCED COMPOSITES

Composites are materials that comprise strong load carrying material (known as reinforcement) imbedded in weaker material (known as matrix). Reinforcement provides Strength and rigidity, helping to support structural load. The matrix or binder (organic or inorganic) maintains the position and orientation of the reinforcement. Significantly, constituents of the composites retain their individual, physical and chemical properties; yet together they produce a combination of qualities which individual constituents would be incapable of producing alone **[19]**.

In composite materials the idea of using cellulose fibers as reinforcement agent is not new and recent one but man had used this idea for a long time, since the beginning of our civilization when straw and grass were used to reinforce mud to make bricks **[20]**.

The history of natural fiber reinforced polymer composites can be traced back to the advent of synthetic polymers in the early part of twentieth century **[21]**.Before this even; examples of the use of natural fibers with natural or semi synthetic polymers exist. For instance ,in 1850s,shellac was being compounded with wood floor in USA with the invention of Bakelite phenolic moulding resin in 1909,it was not long before natural fiber like wood floor was added to from the earliest form of synthetic composites **[20]**.

During the period ,covering the 1920s,1930s and early 1940s ,a good deal of research carried out on natural fiber reinforced composites Caldwell and Clay carried out pioneering work on natural fiber reinforced composites for light materials to be used in aircraft primary structures. Over the last few decades combination of natural fibers like jute ,henequen,sisal,hemp,flax,wood and various grasse with polymer and renewable resources to produce composite materials that are competitive with synthetic composites**[22-31]**. Environmental as well as economic factors are now deriving the trend towards greater utilization of bio based polymers and materials **[32-38]**.

2.2.1 Natural Fibers

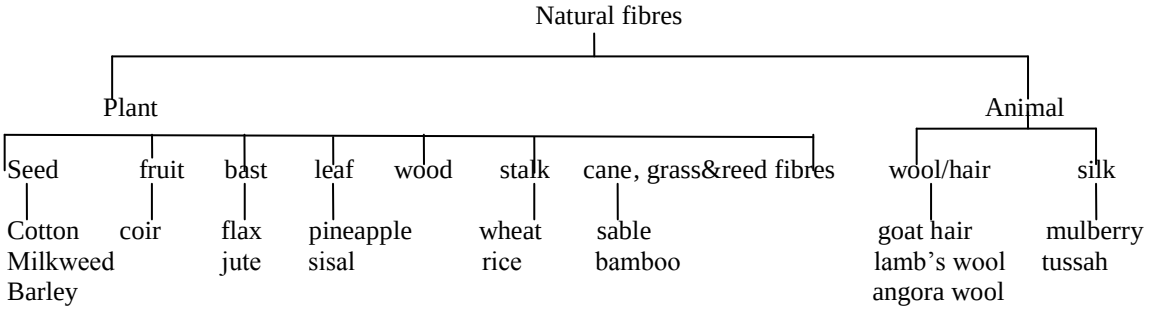
The use of natural fiber for the reinforcement of the composites has received increasing
Attention both by the academic sector and the industry. Natural fibers have many significant advantages over synthetic fibers. Currently, many types of natural fibers **[39]** have been investigated for use in plastics including fl ax, hemp, jute straw, wood, rice husk, wheat, barley, oats, rye, cane (sugar and bamboo), grass, reeds, kenaf, ramie, oil palm empty fruit bunch, sisal, coir, water, hyacinth, pennywort, kapok, paper mulberry, raphia, banana fiber, pineapple leaf fiber and papyrus.
Thermoplastics reinforced with special wood **[40]** fillers are enjoying rapid growth due to their many advantages; lightweight, reasonable strength and stiffness. Some plant proteins are interesting renewable materials, because of their thermoplastic properties. Wheat gluten **[41]** is unique among cereal and other plant proteins in its ability to form a cohesive blend with viscoelastic properties once plasticized. For these reasons, wheat gluten has been utilized to process edible or biodegradable films or packing materials. Hemp **[42]** is a bast lingo cellulosic fiber, comes from the plant *Cannabis sativa* and has been used as reinforcement in biodegradable composites.

Composites based on biologically degradable polyester amide and plant fiber (fl ax and cottons) **[43]** with good mechanical properties, such as sufficient water resistance and biodegradability, have also been investigated.

Kenaf, *Hibiscus cannabinus* L, a member of hibiscus family is also a biodegradable and environmentally friendly crop. It has been found to be an important source of fiber for composites and other industrial applications. Aziz *et al.* **[44]** studied the mechanical properties of composites manufactured from polyester resin with Kenaf fiber that blows to a height of at least 10 meter. Traditionally, hemp has been used to make ropes but these days its fiber is used to make items such as clothing, toys and shoes. The fiber is fully biodegradable, is non-toxic and may be recycled

2.2.2 Types of Natural Fibers

Natural fibres are renewable materials and depending on their source can be subdivided mainly into two major groups: plant fibres and animal fibres.



2.2.3 Natural fibers and countries of origin

Natural fibers **[45]** are generally lingo cellulosic in nature, consisting of helically wound cellulose micro fibrils in a matrix of lignin and hemi cellulose. According to a Food and Agricultural Organization survey, Tanzania and Brazil produce the largest amount of sisal. Henequen is grown in Mexico. Abaca and hemp are grown in the Philippines. The largest producers of jute are India, China, and Bangladesh. Presently, the annual production of

natural fibers in India is about 6 million tons as compared to worldwide production of about 25 million tons. Following table 2.1 provides the fibers and countries of the origin

Table 2.1: Fibers and countries of origin.

Coir	:	India, Sri Lanka, Malaysia, Philippines
Jute	:	India, Egypt, Jamaica, Ghana, Malwali, Sudan
Sisal	:	East Africa, Bahamas, Kenya, India, Tanzania
Abaca	:	Bolivia, Malaysia, Uganda, Philippines
Flax	:	Borneo
Hemp	:	China, Yugoslavia
Kenaf	:	Cuba, Togo, Jamaica, South Africa, Iraq, Tanzania
Sun Hemp	:	India, Guyana, Nigeria

2.2.4 Coir Dust

Coir dust is the spongy, peat like residue from the processing of coconut husks (mesocarp) for coir fiber. Also known as coco peat, it consists of short fibers (<2cm) around 2% - 13% of the total and cork like particles ranging in size from granules to fine dust.

Coir dust strongly absorbs liquids and gases. This property is due in part to the honeycomb like structure of the mesocarp tissue which gives it a high surface area per unit volume. Coir dust is also hydrophilic (attracts water) which means that moisture spreads readily over these surfaces. The extensive film of water that is produced gives moist coir the capacity to absorb air and other gases (odors).

Coir dust is a by-product of coir fiber production which is an important industry in most countries where there are coconuts. Coir fiber is used in a wide variety of ways. Ropes, mats, brushes, furniture, car seat covers, mattresses, packaging, floor coverings, pots and basket

liners, erosion control netting, aquarium filters and absorbent pads for cleaning up oil spills are just some of the inventive applications found for this versatile fiber.

2.2.4.1 Countries of origin for Coir dust

Coir dust is found in most countries where coconuts are grown. The main horticultural supplies for Australia presently come from Sri Lanka and India. However, before the Asian financial crash material was brought in from Indonesia, the Philippines, Malaysia and New Guinea. Pacific countries notably Fiji and Samoa are keen to enter the market but do not have large coir fiber industries.

2.2. 4.2 Applications of the Coir dust

Coir dust is used as a substitute for peat in a growing range of applications.

The local supermarket shelves show that coir dust is now commonly used in retail potting mixes especially those that claim to be water efficient. An indication of its market acceptance is the prominence now given on the bag to the words “Contains coir dust”. This product is no longer the poor cousin of European peat.

The successful substitution of coir for peat in potting mixes has led to other uses. Coir dust is used as a medium for hydroponic production of flowers and vegetables replacing materials like Rockwool, prelate and sawdust. Coir dust is also now used in soil mixes for golf courses. A recent example is the new course north of Sydney called “The Springs “. Coir dust has been trialed as a casing layer in mushroom production and as a biological filter for odour control.

2.2.4.3 Physical Properties

Coir dust is very similar to peat in appearance. It is light to dark brown in colour and consists primarily of particles in the size range 0.2-2.0 mm (75-90%). Unlike sphagnum peat, there are no sticks or other extraneous matter

Coir dust has a similar dry density, water holding capacity (WHC) and available water content as sphagnum peat. The air-filled porosity (AFP) is slightly lower but this is compensated for by a more even distribution of moisture in the mix. This is discussed in more detail later.

Material	**Dry weight** g/L	**%WHC (Australian Standard method)**	**%AFP**
Coir dust	90	69	15
Sphagnum	100	53	25
Sedge peat	55	65	20

Table 2.2: Physical properties of the coir dust [46]

2.2.4.4 Chemical Properties

Coir dust is less acidic than sedge or sphagnum peat and smaller amounts of lime are needed to achieve a pH suitable for growing plants. Table 2.3 gives the chemical properties of the coir dust.

Material	Moisture %	pH	EC dS/m	N %DWt	P	K	Cl
Coir dust	13	5.1	0.80	0.5	0.3	0.4	0.07
Sphagnum peat	9	3.3	0.85	0.9	0.5	0.1	0.05
Sedge peat	83	4.9	0.35	0.9	0.5	0.1	0.05

Table 2.3: Chemical Properties of the coir dust **[46]**.

2.3 MECHANICAL PROPERTIES OF NATURAL FIBERS

The mechanical properties and physical properties of natural fibers vary considerably depending on the chemical and structural composition, fiber type and growth conditions. Mechanical properties **[47]** of plant fibers are much lower when compared to those of the most widely used competing reinforcing glass fibers. However, because of their low density, the specific properties (property-to-density ratio), strength, and stiffness of plant fibers are comparable to the values of glass fibers **[48]**. Table 2.4 gives the various mechanical properties of the natural fiber composites.

Fiber	Density(g/cm³)	Tensile Strength(MPa)	Tensile Modulus(GPa)	Diameter (μm)	Elongation at Break (%)
Cotton	1.5-1.6	287-800	5.5-12.6	…….	7-8
Jute	1.3-1.45	393-773	13-26.5	25.2	1.16-1.5
Flax	1-5	345-1100	27.6	……	2.7-3.2
Sisal	1.45	468-640	9.4-22	50-200	3-7
Hemp	……	690	……..	……..	1.6
Cotton	1.5-1.6	287-800	5.5-12.6	……..	7-8
Abaca	1.35	980	106 Psl	…….	……

Table 2.4: Mechanical properties of the natural fiber composites

Natural fibers have gained renewed interest especially as a glass fiber substitute in automotive industries after decades of development of high performance artificial fibers like carbon, aramid and glass.

2.4 WEAR PROPERTIES OF COMPOSITES

Wear is the erosion of material from a solid surface by the action of another surface. It is related to surface interactions and more specifically the removal of material from a surface as a result of mechanical action**[49]** The need for mechanical action, in the form of contact due to relative motion, is an important distinction between mechanical wear and other processes with similar outcomes**[50]**.

Wear can also be defined as a process in which interaction of the surfaces or bounding faces of a solid with its working environment results in dimensional loss of the solid, with or without loss of material. Aspects of the working environment which affect wear include loads (such as unidirectional sliding, reciprocating, rolling, and impact loads), speed, temperature, type of counter body (solid, liquid, or gas), and type of contact (single phase or multiphase, in which the phases involved can be liquid plus solid particles plus gas bubbles).

2.4.1 Stages of wear

Under normal operating parameters, the property changes during usage normally occur in three different stages as follows:

- Primary or early stage or run-in period, where rate of change can be high.
- Secondary or mid-age process where a steady rate of aging process is maintained. Most of the useful or working life of the component is comprised in this stage.
- Tertiary or old-age stage, where a high rate of aging leads to rapid failure.

With increasing severity of environmental conditions such as higher temperatures, strain rates, stress and sliding velocities, the secondary stage is shortened and the primary stage tends to merge with the tertiary stage, thus drastically reducing the working life. Surface engineering processes are used to minimize wear and extend working life of material **[51-52]**.

2.4.2 Types of wear

The study of the processes of wear is part of the discipline of tribology. The complex nature of wear has delayed its investigations and resulted in isolated studies towards specific wear mechanisms or processes **[53]** .Some commonly referred to wear mechanisms (or processes) include:

1. Adhesive wear
2. Abrasive wear
3. Surface fatigue
4. Fretting wear
5. Erosive wear
6. Corrosive.

A number of different wear phenomena are also commonly encountered and represented in literature. Impact wear, cavitation wear, diffusive wear and corrosive wear are all such examples.

These wear mechanisms; however, do not necessarily act independently in many applications. Wear mechanisms are not mutually exclusive **[50]** "Industrial Wear" is the term used to describe the incidence of multiple wear mechanisms occurring in unison. Wear mechanisms and/or sub-mechanisms frequently overlap and occur in a synergistic manner, producing a greater rate of wear than the sum of the individual wear mechanisms.

2.4.2.1 Adhesive wear

Adhesive wear occurs when two bodies slides over each other, or are pressed into one another, which promote material transfer between the two surfaces. Generally there are two types of adhesive friction.

1. Cohesive adhesive forces, holds two surfaces together even though they are separated by a measurable distance, (i.e., atom/atom or molecules interaction).
2. Adhesive wear, material transfer from one surface to another caused by relative motion, "direct contact" and plastic deformation.

Adhesive wear can also be described as plastic deformation of very small fragments within the surface layer when two surfaces slides against each other. The asperities (i.e., microscopic high points) found on the mating surfaces will penetrate the opposing surface and develop a plastic zone around the penetrating asperity.

2.4.2.2 Abrasive wear

Abrasive wear occurs when a hard rough surface slides across a softer surface **[49]** ASTM (American Society for Testing and Materials) defines it as the loss of material due to hard particles or hard protuberances that are forced against and move along a solid surface **[54]**.

Abrasive wear is commonly classified according to the type of contact and the contact environment **[55]** the type of contact determines the modes of abrasive wear. The two modes of abrasive wear are known as two-body and three-body abrasive wear. Two-body wear

occurs when the grits, or hard particles, are rigidly mounted or adhere to a surface, when they remove the material from the surface. The common analogy is that of material being removed with sand paper. Three-body wear occurs when the particles are not constrained, and are free to roll and slide down a surface. The contact environment determines whether the wear is classified as open or closed. An open contact environment occurs when the surfaces are sufficiently displaced to be independent of one another.

There are a number of factors which influence abrasive wear and hence the manner of material removal. Several different mechanisms have been proposed to describe the manner in which the material is removed. Three commonly identified mechanisms of abrasive wear are:

a. Plowing

b. Cutting

c. Fragmentation

Plowing occurs when material is displaced to the side, away from the wear particles, resulting in the formation of grooves that do not involve direct material removal. The displaced material forms ridges adjacent to grooves, which may be removed by subsequent passage of abrasive particles.

Cutting occurs when material is separated from the surface in the form of primary debris, or microchips, with little or no material displaced to the sides of the grooves. This mechanism closely resembles conventional machining.

Fragmentation occurs when material is separated from a surface by a cutting process and the indenting abrasive causes localized fracture of the wear material. These cracks then freely propagate locally around the wear groove, resulting in additional material removal by spalling **[55]**.

2.4.2.3 Surface fatigue

Surface fatigue is a process by which the surface of a material is weakened by cyclic loading, which is one type of general material fatigue. Fatigue wear is produced when the wear

particles are detached by cyclic crack growth of micro cracks on the surface. These micro cracks are either superficial cracks or subsurface cracks.

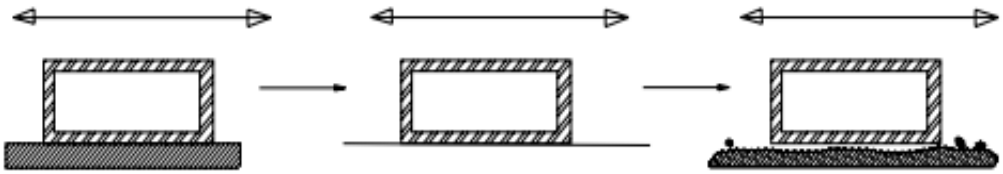


Figure 2.1: Schematic representation of the surface fatigue wear mechanism

2.4.2.4 Fretting wear

Fretting wear is the repeated cyclical rubbing between two surfaces, which is known as fretting, over a period of time which will remove material from one or both surfaces in contact. It occurs typically in bearings, although most bearings have their surfaces hardened to resist the problem. Another problem occurs when cracks in either surface are created, known as fretting fatigue. It is the more serious of the two phenomena because it can lead to catastrophic failure of the bearing. An associated problem occurs when the small particles removed by wear are oxidized in air. The oxides are usually harder than the underlying metal, so wear accelerates as the harder particles abrade the metal surfaces further.

2.4.2.5 Erosive wear

Erosive wear is caused by the impact of particles of solid or liquid against the surface of an object **[56]**. The impacting particles gradually remove material from the surface through repeated deformations and cutting actions **[57]**. It is a widely encountered mechanism in industry. A common example is the erosive wear associated with the movement of slurries through piping and pumping equipment.

The rate of erosive wear is dependent upon a number of factors. The material characteristics of the particles, such as their shape, hardness, and impact velocity and impingement angle are primary factors along with the properties of the surface being eroded. The impingement angle is one of the most important factors and is widely recognized in literature **[58]**. For ductile materials the maximum wear rate is found when the impingement angle is approximately 30°,

whilst for non ductile materials the maximum wear rate occurs when the impingement angle is normal to the surface **[58]**.

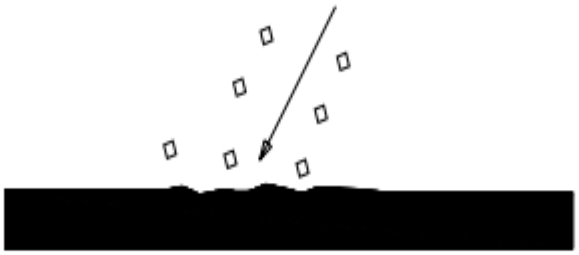


Figure 2.2: Schematic representation of the erosive wear mechanism

2.4.2.6 Corrosive wear

Most metals are thermodynamically unstable in air and react with oxygen to form an oxide, which usually develop layer or scales on the surface of metal or alloys when their interfacial bonds are poor. Corrosion wear is the gradual eating away or deterioration of unprotected metal surfaces by the effects of the atmosphere, acids, gases, alkalis, etc. This type of wear creates pits and perforations and may eventually dissolve metal parts.

2.4.3 Erosive wear characteristics of the polymer composites

Solid particle erosion is the progressive loss of original material from a solid surface due to mechanical interaction between that surface and solid particles. Polymers and their composites have generated wide interest in various engineering fields, particularly in aerospace applications, in view of their good strength and low density as compared to monolithic metal alloys. There have been various reports of applications of polymers and their composites in erosive wear situations in the literature **[59–61]**.

Polymers are finding an ever increasing application as structural materials in various components and engineering systems. The high specific strength and stiffness of polymers are primarily responsible for their popularity. However, the resistance of polymers to solid particle erosion has been found to be very poor [**62**], and in fact it is two or three orders of magnitude lower than metallic materials [**63**]. One possible way to overcome such a shortcoming is to introduce a hard second phase in the polymer to form polymer matrix composites (PMCs). A number of investigators [**62-69**] have evaluated the resistance of various types of PMCs to solid particle erosion. Tilly and Sage **[64]** tested nylon and epoxy reinforced with various fibers such as graphite, glass and concluded that the reinforcement can either increase or decrease the erosion resistance depending on the type of fibers. Zahavi and Schmitt [**63**] tested a number of PMCs for erosion resistance and concluded that glass-reinforced epoxy composite had a particularly good erosion resistance**.** The above study was extended further by Tsiang [**65**]. He carried out sand erosion tests on a wide range of thermo set and thermoplastic PMCs having glass, graphite and Kevlar fibers in the forms of tape, fabric and chopped mat as reinforcements. Kevlar fibers in an epoxy resin provided the best erosion resistance.

In a recent study, Mathias et al. [**66**] and also Karasek et al**. [67]** have evaluated the erosion behavior of a graphite fiber reinforced bismaleimide polymer composite. These investigators observed the erosion rates of the PMC to be higher than the unreinforced polymer. Many of the investigators [**63-69**] also consistently noted that the erosion rates of the PMCs were considerably larger than those obtained in metallic materials. In addition, composites with a thermosetting matrix mostly exhibited a maximum erosion rate at normal impact angles (i.e. a brittle erosion response) while for the thermoplastic polymer composites the erosion rate reached a maximum at an intermediate impact angle in the range 400-500 signifying a semi ductile erosion response.

Cellulosic fibers, like sisal, henequen, jute, oil palm, bamboo, wood paper in their natural condition, as well as, several waste cellulosic products such as shell flour, wood flour and pulp have been used as reinforcement agents of different thermosetting and thermo plastic resins **[70-79]**. During leaf deliberation of henequen fibers and also during the transformation of the raw fibers into cordage, approximately 10 % of waste fibers are produced **[77]**.These waste fibers could be profitably used in the manufacture of fiber polymer reinforced composites because they posses attractive physical and mechanical properties**[79]**.Natural fibers having the unique properties such as bio degradability ,environmental friendliness, low cost ,less density , high specific strength and

so forth have shifted the focus of researches from synthetic to natural fiber –reinforced polymer matrix composites.

The interest in natural fiber reinforced polymer composite materials is rapidly growing in terms of their tribological ,industrial applications and fundamental research**[80]**.There are some possibilities where the composite may encounter impacts of lot of abrasions from splinters of materials ,sand and slurry of solid particles so consequently the material may failure due to erosion wear. Hence, the study of erosion behavior of natural fiber reinforced polymer composite is vital importance. The erosion wear of reinforced polymer composite is usually higher than unreinforced polymer matrix **[81]**.The erosion resistance of polymer composite is low in comparison to monolithic materials **[82]**.

2.4.4 Abrasive wear characteristics of the polymer composites

Abrasive wear occurs when a hard rough surface slides across a softer surface [**83**]. ASTM (American Society for Testing and Materials) define it as the loss of material due to hard particles or hard protuberances that are forced against and move along a solid surface [**84**]. Abrasive wear is commonly classified according to the type of contact and the contact environment [**85**]. The type of contact determines the mode of abrasive wear. The two modes of abrasive wear are known as two-body and three-body abrasive wear. Two-body wear occurs when the grits, or hard particles, are rigidly mounted or adhere to a surface, when they remove the material from the surface. The common analogy is that of material being removed with sand paper. Three-body wear occurs when the particles are not constrained, and are free to roll and slide down a surface. The contact environment determines whether the wear is classified as open or closed. An open contact environment occurs when the surfaces are sufficiently displaced to be independent of one another.

Several researchers have reported on the abrasive wear behavior of fiber reinforced polymer composites [**86-88**]. It is important to note that the fiber reinforcement (short, long, and continuous) in polymer increases the wear resistance and reduces coefficient of friction in the case of sliding wear. It does not automatically mean that these materials will perform better when sliding under abrasive wear situations, but often the opposite trend results. The influence of fiber and/or fillers on the abrasive wear performance of polymer is a more complex and unpredictable phenomenon [**89**]. Chand et al. [**90**] studied low stress abrasive

wear behavior of short E-glass fiber reinforced polymer composites with and without fillers by using rubber wheel abrasion test apparatus. They reported that higher weight fraction of glass fibers (45%) in the composites improves the wear resistance as compared to the composite containing less glass fibers (40%). Evans et al. [**91**] studied the abrasion wear behavior for 18 polymers and they noticed that low density polyethylene (LDPE) showed the lowest wear rate in abrasion against rough mild steel, but a higher wear rate in abrasion with coarse corundum paper. Budinski [**92**] investigated the abrasion resistance of plastics and concluded that the abrasion resistance of plastics is inconclusive and recommended for further study. Cenna et. al. [**93**] studied abrasion resistance of three types of vinyl ester resin systems, i.e., un-reinforced, reinforced with glass fibers, and reinforced with particles of ultra-high molecular weight polyethylene (UHMWPE). They found that UHMWPE reinforced composites showed enhanced wear resistance against both coal and mineral ignimbrite used as abrasives. Cirino et al. [**94, 95**] investigated the sliding and abrasive wear behavior of poly-ether-etherketone (PEEK) with different continuous fiber types and reported that the wear rate decreases with increase in the fiber content and also studied the mechanisms of abrasive wear using scanning electron microscopy and discussed the topic by schematic illustrations of basic wear phenomena. The abrasive wear behavior of short carbon/glass fiber reinforced with PEEK/polyphenylene sulfide (PPS) thermoplastic polymers was reported by Lhymn et al. [**96**] and they concluded that the wear rate is sensitive to the fiber orientation axis with respect to the sliding direction. The normal oriented specimen showed a lower wear rate than the anti-parallel or parallel specimen. Friedrich [**97**] has reported that the wear rate of thermoplastics is not improved by adding short fibers if the wear mechanism is highly abrasive in nature. In contrast, in the case of continuous fiber reinforcement, an increased wear resistance has been reported.

Mainly, work has been reported on the sliding-wear behavior of fiber-reinforced polymer composites. Bijwe et al. [**98**] have investigated a polyetherimide short glassfibre- reinforced composite for sliding wear against a mild steel counter face and have concluded that the results may be compared with the performance of commercially available bearing materials. Researchers [**99-115**] have also reported friction and wear of some advanced composites. The main emphasis has been given to the friction and wear of unidirectional, continuous, fiber-reinforced polymer composites. Most of them concluded that the wear of the material is not

an intrinsic property but rather depends on the volume fraction, as well as the type and direction of orientation with respect to the sliding direction. Tsukizoe and Ohmae [**115**] derived an empirical wear equation for advanced composites and finally concluded that wear of composites proceeded by wear thinning of the reinforcement. Subsequently, fiber breaking and peeling-off of the fibers occurs. Bahadur and Zheng [**116**] found that the sliding wear rate is a function of the fiber weight fraction, for short fiber-reinforced polyester composites. Tewari and Bijwe [**117**] in their paper on the abrasive wear of polyimide and particulate filled composites observed that load and particle size are important parameters that affect the wear characteristics. Chand and Fahim [**118**] used polyester and epoxy resins reinforced with glass fibers in woven form for abrasive wear studies and derived a theoretical model for the specific wear rate of their composites. Lhymn et al. [**119**] reported, for short fiber-reinforced polyester composites, that the wear rate is sensitive to the orientation of the fiber axis with respect to the sliding direction, that a ploughing mechanism is evident and that the correlation between the wear factor and the friction coefficient is not clear. The limited literature on the abrasive wear limits the level of understanding for two-body abrasive wear.

2.5 DIELECTRICS

A dielectric is an electrical insulator that may be polarized by the action of an applied electric field. When a dielectric is placed in an electric field, electric charges do not flow through the material, as in a conductor, but only slightly shift from their average equilibrium positions causing dielectric polarization. Because of dielectric polarization, positive charges are displaced along the field and negative charges shift in the opposite direction. This creates an internal electric field which partly compensates the external field inside the dielectric **[120,121]** if a dielectric is composed of weakly bonded molecules, those molecules not only become polarized, but also reorient so that their symmetry axis aligns to the field **[122].**

While the term "insulator" refers to a low degree of electrical conduction, the term "dielectric" is typically used to describe materials with a high polarizability. The latter is expressed by a number called the dielectric constant. A common, yet notable, example of a dielectric is the electrically insulating material between the metallic plates of a capacitor. The

polarization of the dielectric by the applied electric field increases the capacitor's capacitance **[122]** .

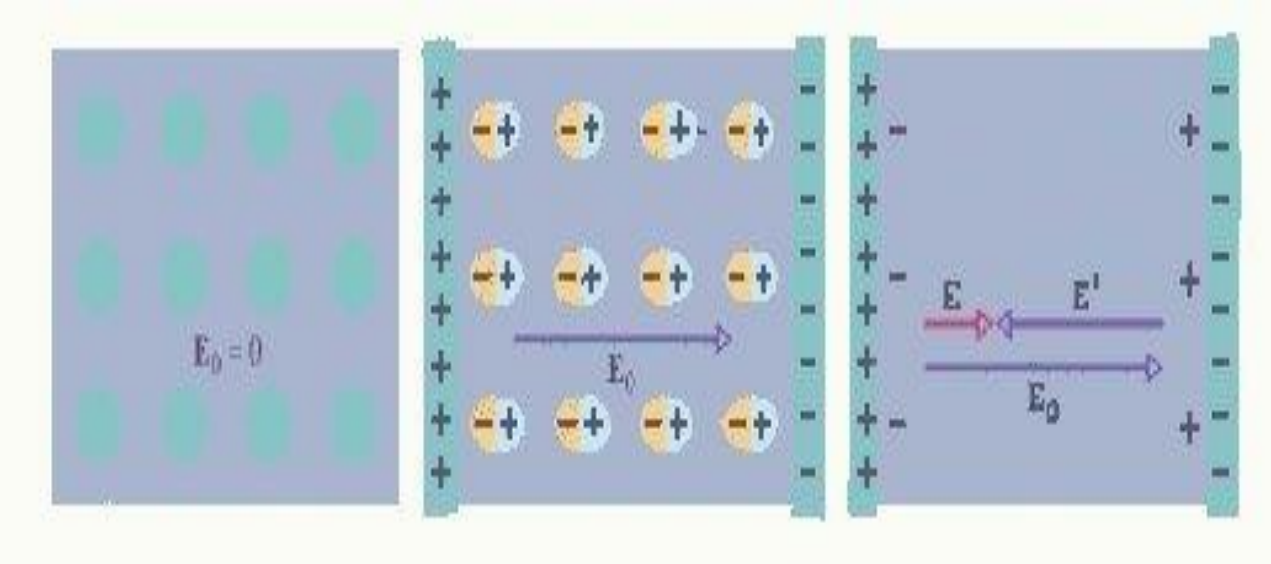


Figure 2.3: Polarization of the dielectric material between the capacitor plates

The study of dielectric properties is concerned with the storage and dissipation of electric and magnetic energy in materials **[123]**. It is important to explain various phenomena in electronics, optics, and solid-state physics.

2.5.1 Dielectric Mechanisms

There are a number of different dielectric mechanisms, connected to the way a studied medium reacts to the applied field (see the figure illustration). Each dielectric mechanism is centered around its characteristic frequency, which is the reciprocal of the characteristic time of the process. In general, dielectric mechanisms can be divided into relaxation and resonance processes. The most common, starting from high frequencies, are:

2.5.1.1 Electronic polarization

This resonant process occurs in a neutral atom when the electric field displaces the electron density relative to the nucleus it surrounds.

This displacement occurs due to the equilibrium between restoration and electric forces. Electronic polarization may be understood by assuming an atom as a point nucleus surrounded by spherical electron cloud of uniform charge density.

2.5.1.2 Atomic polarization

Atomic polarization is observed when the electronic cloud is deformed under the force of the applied field, so that the negative and positive charge is formed. This is a resonant process.

2.5.1.3 Dipole relaxation

This originates from permanent and induced dipoles aligning to an electric field. Their orientation polarisation is disturbed by thermal noise (which miss-aligns the dipole vectors from the direction of the field), and the time needed for dipoles to relax is determined by the local viscosity. These two facts make dipole relaxation heavily dependent on temperature and chemical surrounding.

2.5.1.4 Ionic relaxation

Ionic relaxation comprises ionic conductivity and interfacial and space charge relaxation. Ionic conductivity predominates at low frequencies and introduces only losses to the system. Interfacial relaxation occurs when charge carriers are trapped at interfaces of heterogeneous systems. A related effect is Maxwell-Wagner-Sillars polarization, where charge carriers blocked at inner dielectric boundary layers (on the macroscopic scale) or external electrodes (on a macroscopic scale) lead to a separation of charges. The charges may be separated by a considerable distance and therefore make contributions to the dielectric loss that are orders of magnitude larger than the response due to molecular fluctuations**[121]**.

2.5.1.5 Dielectric relaxation

Dielectric relaxation as a whole is the result of the movement of dipoles (dipole relaxation) and electric charges (ionic relaxation) due to an applied alternating field, and is usually observed in the frequency range 10^2-10^{10} Hz. Relaxation mechanisms are relatively slow

compared to resonant electronic transitions or molecular vibrations, which usually have frequencies above 10^{12} Hz.

2.5.2 Dielectric nature of the polymer composites

It is well known that composites can be produced exhibiting enhanced properties that the constituent materials may not exhibit **[124-127]**. For instance, from the combination of different fibers or fillers with polymer matrices one can produce polymer-matrix composites, a material important to the electronic industry for its dielectric properties in the use of capacitors **[128-130]**. The effective utilization of filled polymers depends strongly on the ability to disperse the fillers homogeneously throughout the matrix **[131]**. The interface properties also strongly affect the characteristics and performance of these composites **[132]**. One of the most attractive features of these filled composites is that their dielectric properties can be widely changed by choice of shape, size, and the conductivity of filled constituents in the polymeric matrix.

Most of the interesting properties of polymers are attributable to the complex motions within their molecular matrix. In the polymeric system, molecular relaxations exhibit various transitions **[133]**. As very little work has been reported on double-layer systems, the intention in the present work is to study dielectric properties of such a system. The polymeric interfaces act as charge-carrier trapping sites **[134]**. Therefore, it has become essential to study the effect of interfaces on the charge-carrier generation, transport and storage in polymeric systems. The study of dielectric constant and dielectric loss, as a function of temperature and frequency is one of the most convenient and sensitive methods of studying polymeric structure.

For polymer composites in the solid or viscoelastic state, the physical structure is of great importance in determining the dielectric behavior **[135]**. The dielectric properties of polymer composite materials have been studied with a view to modifying the properties of polymer systems for practical applications. The conventional inorganic insulators and dielectrics have to a large extent been replaced by polymers on account of their unique ability to be tailor made for specific needs. Epoxies and polyesters have been used in electronics as insulators,

dielectrics, substrates, potting compounds, embedding materials and conformal coatings **[136]**.

2.6 CHEMICAL TREATMENT OF NATURAL FIBERS

One of the major problems associated with the use of natural fibers in composites is their high moisture sensitivity leading to severe reduction of mechanical properties and delaminating. The reduction in mechanical properties may be due to poor interfacial bonding between resin matrices and fibers. It is therefore necessary to modify the fiber surface to render it more hydrophobic and also more compatible with resin matrices. An effective method of chemical modification of natural fibers is graft copolymerization. The resulting co-polymer displays the characteristic properties of both fibrous cellulose and grafted polymer **[137,138]**. One of the most explored chemical modifications is the acetylation-esterifi cation of cellulose-OH, by reaction with acetic anhydride. This reaction reduces hydrophilicity and swelling of lignocelluloses and their composites **[139]**.

The effect of chemical treatment of natural fibers with sodium alginate and sodium hydroxide has also been reported for coir, banana and sisal fibers by Mani *et al.* **[140]**. This modification results in an increase in adhesive bonding and thus improves ultimate tensile strength up to 30%. Mitra *et al.* **[141]** have reported that treatment of jute with polycondensates such as phenol-formaldehyde, melamine-formaldehyde and cashew nut shell with liquid formaldehyde improves the wet ability of jute fibers and reduces water regain properties. Samal and Ray **[142]** have studied the chemical modification of pineapple leaf fibers using alkali treatment, diazo coupling with aniline and cross-linking with formaldehyde. These chemical treatments result in significant improvements in mechanical properties, chemical resistance and reduced moisture regain. Finally, Joseph *et al.* **[143]** have investigated the influence of chemical treatment with sodium hydroxide, isocyanate and peroxide on the properties of sisal/polyethylene composites. The observed enhancement in properties of the composites and attributed this to the strong bonding between sisal and polyethylene matrix.

In an effort to improve the mechanical properties of recycled HDPE/wood fiber composites, Selke *et al.* **[144]** investigated the use of several additives with possible effect on the fiber/matrix adhesion or fiber dispersion into the matrix. They found that maleic anhydride modified polypropylene appears especially promising, since its use at a concentration of 5% in composites with 30% wood fiber results in an increase in tensile strength and elongation at break. Similar results have been obtained by Dalvag *et al.* **[145]**, who have reported that the composite's elastic modulus remains unchanged. Zadorecki and Flodin **[146]** have found that some coupling agents, namely trichloro-striazine and di-methylol melamine can produce covalent bonds between cellulosic materials and polymer matrices, leading to modified performance and reduced sensitivity to water. This approach has been further explored by Maldas and Kokta **[147]**, who used ophthalmic anhydride as coupling agent for wood fiber/polystyrene composites. In addition to the chemical affinity of the benzene rings of ophthalmic anhydride with those of polystyrene, the anhydride group can directly attack the –OH group of cellulose. Furthermore, Razi *et al.* **[148]** found that the treatment of wood with sodium hydroxide followed by drying with vinyltrimethoxysilance is superior, for obtaining maximum bonding strength at the wood/polymer interface that yields improved mechanical properties.

Chapter 3

MATERIALS AND METHODS

- Introduction
- Matrix material
- Composite fabrication
- Physico-Mechanical characterization
- Density and void fraction
- Hardness Test
- Flexural Test
- FTIR Spectroscopy
- Scanning Electron Microscopy
- Dielectric Analysis
- Erosion Wear Tests
- Abrasive Wear Tests
- Chemical treatment of the composite

CHAPTER 3

MATERIALS AND METHODS

3.1 INTRODUCTION

This chapter describes the materials used for the processing of composites and deals with the details of the experimental procedures (such as erosive & abrasive wear tests, hardness tests, flexural test, and dielectric test) followed in this study. After preparation of the composite materials have been subjected to a series of tests, e.g., micro structural characterization of the fracture and worn surfaces, micro hardness measurement, flexural strength test, erosion test, abrasion test, dielectrical measurements etc. The details of each process are described here.

3.2 MATRIX MATERIAL

Epoxy LY 556, chemically belonging to the 'epoxide' family is used as the matrix material. Its common name is Bisphenol A Diglycidyl Ether. The hardener with IUPAC name NN0-bis (2-aminoethylethane-1, 2-diamin) used with the epoxy has the designation HY-951. The epoxy resin and the hardener were supplied by Ciba Geigy India Ltd. Resin and hardeners are mixed in a ratio of 10:1 by weight as recommended. Density of the epoxy resin system is 1.28 g/cc.

3.3 COMPOSITE FABRICATION

Coir dust was mixed with the epoxy resin by stirring at room temperature and poured in moulds of dimensions (300 ×300× 5) mm. Five samples i.e. sample A(pure epoxy),sample B(epoxy+10 wt% of coir dust),sample C(epoxy+20 wt% of coir dust),sample D(epoxy+40wt% of coir dust),and sample E(epoxy+60 wt% of coir dust) are prepared . Test specimens of suitable dimensions are cut from the composite sheets for erosion wear test. For abrasive wear test, composite pins of length30 mm and diameter of 10 mm are prepared by using cylindrical moulds. The fabricated samples are shown in figure 3.1.

Designation	Composition
ECD1 (Sample A)	Pure Epoxy
ECD2 (Sample B)	Epoxy + 10 wt % Coir Dust
ECD3 (Sample C)	Epoxy +20 wt % Coir Dust
ECD4 (Sample D)	Epoxy +40wt % Coir Dust
ECD5 (Sample E)	Epoxy + 60 wt % Coir Dust

Table3.1 Different wt% percentages of the coir dust in epoxy resin.

Figure 3.1: shows different Coir Dust reinforced epoxy composites

3.4 PHYSICO-MECHANICAL CHARACTERIZATION

3.4.1 Density and void fraction

The bulk density and void fraction of the composite materials be obtained from following equations by using archemidus principle.

$$\text{Density} = \frac{\text{Dry weight}}{(\text{soaked weight} - \text{suspended weight})}$$

$$\text{Apparent porosity} = \frac{(\text{Soaked Weight} - \text{Dry Weight})}{(\text{Soaked Weight} - \text{Suspended Weight})} \times 100$$

3.4.2 Flexural strength

To evaluate the value of flexural strength (FS), the short beam shear (SBS) tests (generally it is a3-point bend test) are performed on the samples at room temperature. The SBS test is conducted as per ASTM D2344-84 using the Instron 1195 UTM. Here the span length is 40 mm and the cross head speed is 5 mm/min are maintained.

The FS of any composite can be calculated by using the following formula

$$FS = \frac{3FL}{2bt^2}$$

Where F- is the applied load, L- span length, t and b are the thickness and width of the specimen respectively.

Figure 3.2: Loading arrangements for the specimens in Instron 1195

3.4.3 Measurement of Hardness

Leitz Micro –hardness tester was used for Hardness measurement (shown in figure 3.3) this tester had a diamond indentater, in the form a right pyramid with a square base and an angle 136° between opposite faces, is forced in to the material under a load F. After removal of the load the two diagonals X and Y of the indentation left on the surface of the material are measured and their arithmetic L is calculated.

In this present study we considered the load F= 0.3 Kgf and Vickers hardness number is calculated by using the following formula.

$$Hv=0.1889\ F/L^2$$

$$L=(X+Y)/2$$

Where F – is the applied load, L- is the diagonal of square impression (mm), X- is the horizontal length (mm), and Y- is the vertical length (mm).

Figure 3.3: Hardness indenter

3.5 FTIR SPECTROSCOPY

Fourier Transform Infrared (FTIR) spectroscopy is an important analysis technique which detects various characteristic functional groups in molecules of any matter [**149**]. On interaction of an infrared light with the matter, chemical bonds will stretch, contract and bend and as a result, each chemical functional group tends to absorb infrared radiation in a specific wavelength range regardless of the structure of the rest of the molecule. Based on this principle, functional groups present in composite materials are identified. It is performed in a FTIR spectrophotometer interfaced with IR microscope operated in reflectance mode. The microscope is equipped with a video camera, a liquid nitrogen cooled mercury cadmium telluride (MCT) detector and a computer controlled translation stage, programmable in the x and y directions. The spectra are collected in the 400 cm^{-1} to 4000 cm^{-1} regions with 8 cm^{-1} resolution, 60 scans and beam spot size of 10μm-100μm. The FTIR imaging in the present investigation is carried out using a Perkin Elmer Spectrum RX (1).

3.6 SCANNING ELECTRON MICROSCOPY

The morphology and fracture surface of the composites are examined with scanning electron microscope JEOL JSM-6480LV.Composites are coated with 100 A° thick platinum in JEOL sputter ion coater to enhance the conductivity of the samples and observed SEM at 20 kV.

3.7 DIELECTRIC ANALYSIS

Dielectric measurements were carried out with a solartron 1296 Dielectric Interface (shown in figure 3.5) Instrument allowing measurements over the temperature range from 30 C to 150 C and frequency interval from 100Hz to 1 MHz In dielectric analysis, the upper and lower surface of the sample is coated with silver paint for the purpose of conductance, the sample is placed between the two Al parallel electrodes. A sinusoidal signal is applied, creating an alternating electric field. This electric field produce polarization in the sample ,

which oscillates at the same frequency as of the applied electric field, but has a phase angle shift δ .This phase angle shift is measured by comparing the applied voltage to the measured current , which is separated in to capacitive and conductive components **[150-151]** .

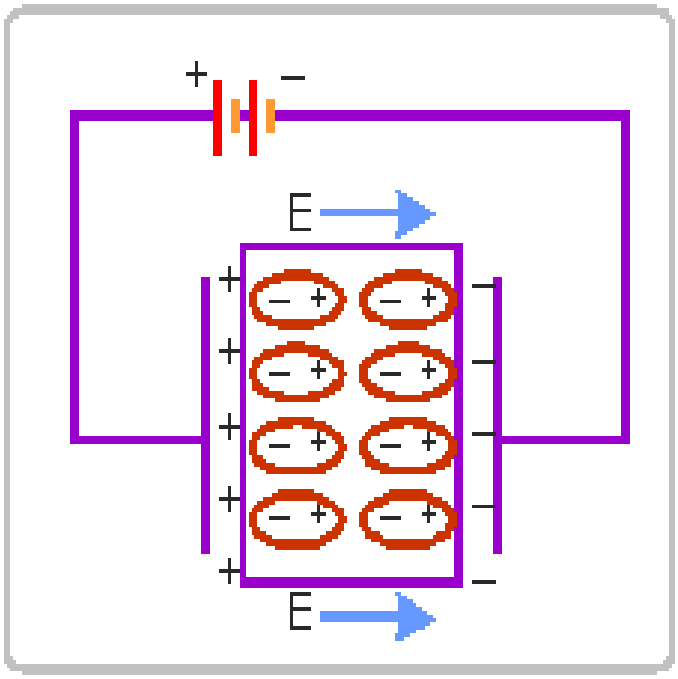


Figure 3.4: Schematic diagram of the applied electric field for a composite

The dielectric constant, dielectric loss, conductivity and resistivity are determined as follows.

Dielectric constant $K = C'/C$.

Where C' (pF) is measured capacitance and C (pF) is calculated using the formulae,

$$C = \varepsilon_0 . (A/d);$$

A ($m.m^2$) - area of the electrode, d (m. m)-thickness of the sample.

The dielectric loss is given by, $\tan \delta = G(S)/ (w\ C' (F))$,

$w=2\pi f$, f-is the measuring frequency. And , $G=G_0(R-R_0)$ **[152]**

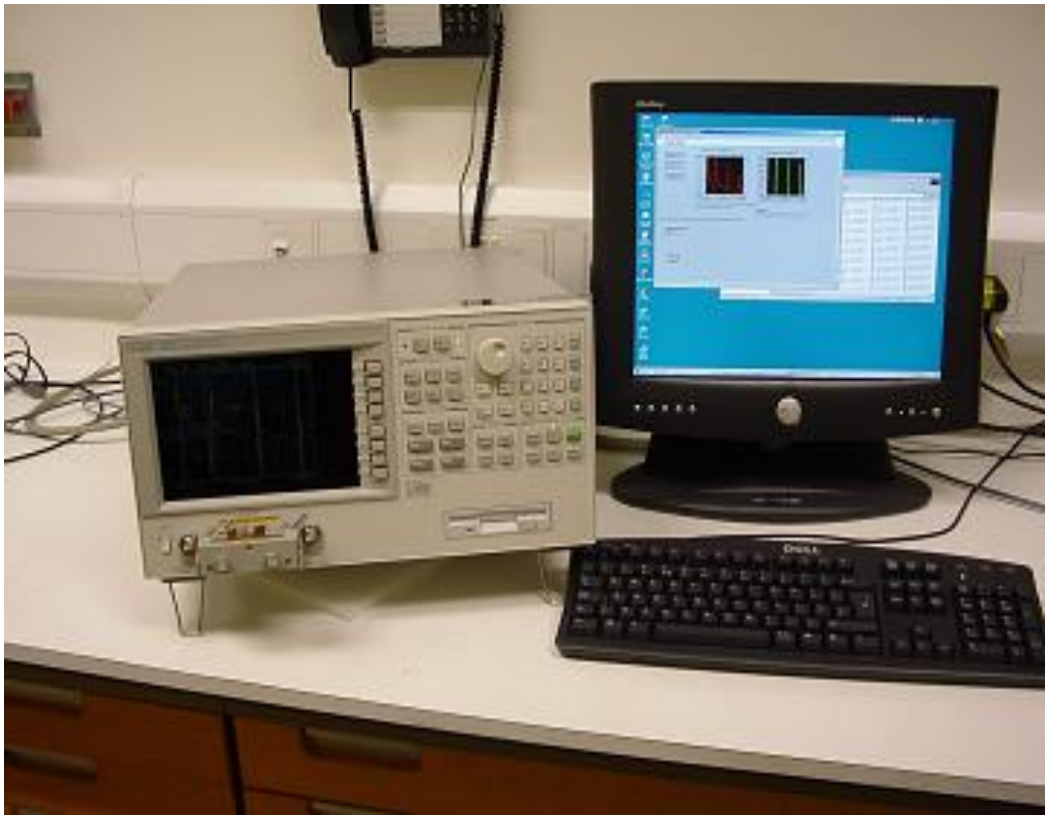


Figure 3.5: Dielectric interface equipment

3.8 EROSION WEAR TESTS

The solid particle erosion tests were carried out as per ASTM G76 standard on the erosion test rig (shown in figure 3.6). It consists of an air compressor, an air particle mixing chamber and accelerating chamber. Dry compressed air is mixed with the erodent particles, which are fed at constant rate from a sand flow control knob through the nozzle tube and then accelerated by passing the mixture through a convergent brass nozzle of 3mm internal diameter. These particles impact the specimen, which can be held at different angles with respect to the direction of erodent flow using a swivel and an adjustable sample clip. Square samples of size 40mm×40mm are cut from the plaques for erosion tests. The velocity of the eroding particles is determined using standard double disc method **[153]**. In the present study, dry silica sand (spherical) of different particle sizes (200µm, 300µm, 400 µm, 500µm and 600 µm) are used as erodent. A standard test procedure is employed for each erosion test.

The samples are weighed to an accuracy of ± 0.1 mg using an electronic balance, eroded in test rig for 5 min. and then weighed again to determine the weight loss. The ratio of weight loss to the weight of the eroding particles causing loss (i.e. testing time ×particle feed rate) is then computed as the dimensionless incremental erosion rate. This procedure repeated till the erosion rate attains a constant steady-state value.

The wear rate was expressed in terms of $\Delta w_1 / \Delta w_2$

Where Δw_1 -is the loss in weight of the composite.

Δw_2 – is the total weight of the erodent used.

Experimental Details showed in the following Table 6.

Impingement angle	30° , 45° ,60° ,75° ,90°
Impact velocity	34 ,48 ,60 ,78 ,92 m/sec
Duration of erosion	25 min
Flux rate	0.650 g/min

Table 3.2: Erosion Test Experimental Details

Figure 3.6: Air jet erosive test rig as per ASTM G76

3.9 ABRASIVE WEAR TESTS

Abrasive wear tests are carried out in pin-on-disc type friction and wear monitoring test rig (shown in figure 3.7) (supplied by DUCOM) as per ASTM G99.The coir dust composite specimen (of size 10mm dia. And 15 mm length) were abraded against the waterproof SiC paper (having 400 μm grit size), fixed on the rotating disc .The specimen is held stationary and the disc is rotated while a normal force is applied through a lever mechanism. A series of tests are conducted for sliding distances 20,40,60,80,and 100 m under different normal loadings of 5,10,15,20,and 25N with test speed of 0.54m/sec .The material loss from the

composite surface is measured by using a precision electronic balance and then the specific wear rate(mm^3/N-m) is then expressed on volume loss basis as;

$$W=\Delta m/ (\rho tVF)$$

Where Δm is the mass loss (in gm), ρ is the density of the composite (gm/mm^3), t is the test duration (sec), V is the sliding velocity (m/sec), and F is the avg normal load (N).

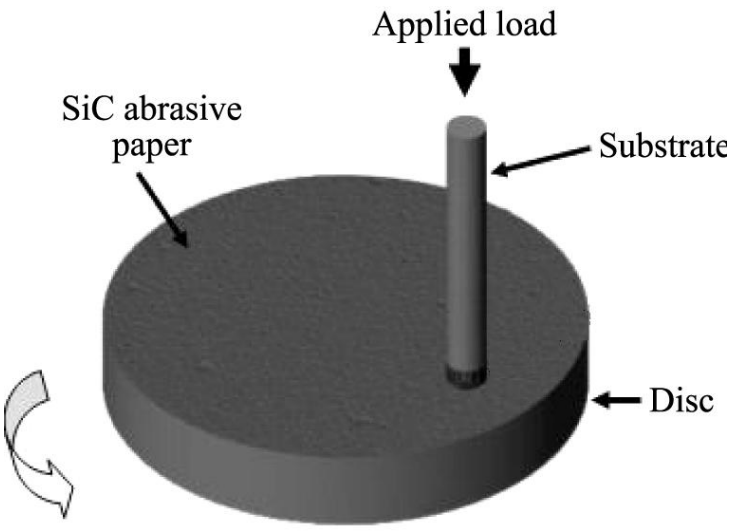


Figure 3.7: Schematic diagram of pin on disc set up

3.10 CHEMICAL TREATMENT OF THE COMPOSITE

Coir dust is the spongy, peat like residues get this from the processing of coconut husks (mesocarp) for coir fiber .The coir dust was washed and sun dried. The dried coir dust was treated with chemicals such as HCl, CH_3COOH, KOH and NaOH.

Total Coir dust was divided in to three equal weights and given the names Sample A, Sample B and Sample C.

The sample A was treated with 1.5M NaOH solution (500ml) inside a beaker and this beaker was put in furnace at 60^0C for 12 hours. The insoluble residue was treated with 5 wt% H_2O_2 (450) and 1.5M NaOH solution at 70^0C for 10 hours and was finally treated with 2.5M NaOH solution (500ml) at 75^0C for 3 hours. After completion of the treatment, composite (with 20 wt% of coir dust) has prepared by hand lay-up method.

The sample B was treated with 1.5M NaOH solution (500ml) inside a beaker and this beaker was put in furnace at 60^0C for 12 hours. The insoluble residue was treated with 5 wt% H_2O_2 (450) and 1.5M NaOH solution at 70^0C for 10 hours and was finally treated with 2M HCl solution (500ml) at 60^0C for 3 hours. After completion of the treatment, composite (with 20 wt% of coir dust) has prepared by hand lay-up method.

The sample C was treated with the 2M KOH (450ml) solution at 60^0C for 12 hours. The insoluble residue was delignified with 2% NaCl solution (500ml) at pH 3, and adjusted with 10 wt% acetic acid at 60^0C for 1 hour. Another treatment with KOH solution (300ml) under the same conditions as the first step was used. After completion of the treatment, composite (with 20 wt% of coir dust) has prepared by hand lay-up method.

Chapter summary

This chapter has provided:

- The descriptions of materials used in the experiments.
- The details of fabrication and characterization of the composites.
- The description of erosion and abrasive wear test.
- The description of dielectric test.
- The description of chemical treatment of the coir dust.

The next chapter presents the physic- mechanical and dielectrical properties of the polymer Composites under study.

Chapter 4

RESULTS AND DISCUSSION

- Introduction
- Physico-Mechanical properties of composites
- Density and void fraction
- Hardness
- Flexural Strength
- Dielectric Properties
- Study of abrasion wear behavior
- Study of Erosion wear behavior
- Effect of chemical treatment on the properties of composite

CHAPTER 4
RESULTS AND DISCUSSION

4.1 INTRODUCTION

Bio-waste coir dust reinforced polymer composites are prepared using epoxy as the matrix. Epoxy LY 556, chemically belonging to the 'epoxide' family is used as the matrix material. Its common name is Bisphenol A Diglycidyl Ether. The hardener with IUPAC name NN0-bis (2-aminoethylethane-1, 2-diamin) used with the epoxy has the designation HY-951. The epoxy resin and the hardener were supplied by Ciba Geigy India Ltd. Resin and hardeners are mixed in a ratio of 10:1 by weight as recommended. The results of various tests are presented and discussed in this chapter.

4.2 Physico – Mechanical Properties of Composites

4.2.1 Density and void fraction

The theoretical density of composite material in terms of weight fraction can easily be obtained by equation of Agarwal and Broutman. The actual density of the composite, however, can be determined experimentally by simple water immersion technique by using Archimedes principle.

The density of coir dust is about 0.12 gm/cm³ and that of epoxy resin is about 1.11 gm/cm³ the density of the new material decreases with an increase of coir dust content as shown in table 4.1, for coir dust reinforced epoxy composites.

Sample	Density (gm/cm³)	Void fraction (%)
Pure Epoxy	1.1965	0.2732
Epoxy + 10 wt % Coir Dust	1.15115	0.4957
Epoxy +20 wt % Coir Dust	1.1107	0.8807
Epoxy +40wt % Coir Dust	1.0562	0.9899
Epoxy + 60 wt % Coir Dust	1.033	1.0177

Table 4.1: Variation of density and Void fraction (%) with different wt% of Coir dust, reinforced in epoxy matrix.

Figure 4.1 gives the variation of density, and void fraction of the coir dust reinforced epoxy matrix composite. The density of the new material decreases with increase of coir dust content as shown in the figure 4.1(a).This is due to presents of high air content(from 24% to 89% by volume).With addition of coir dust in epoxy resin the volume fraction of voids is increased. The voids significantly affect some of the mechanical properties and even the performance of the composites in the place of use.

(a) (b)

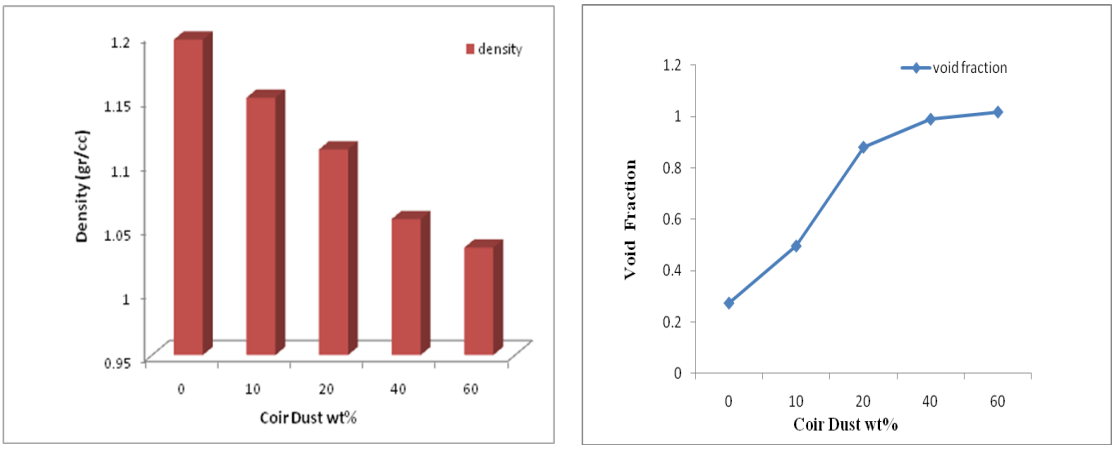


Figure 4.1 Variation of the (a) Density (b) Void fraction of composites with wt% of coir dust reinforced epoxy composites.

4.2.2 Hardness

Figure 4.2 gives the hardness values of all different weight percentage of coir dust reinforced composites.It can be visualized that the hardness of the material decreased with increasing the reinforcement content , due to softness of the coir dust compare with the matrix material.

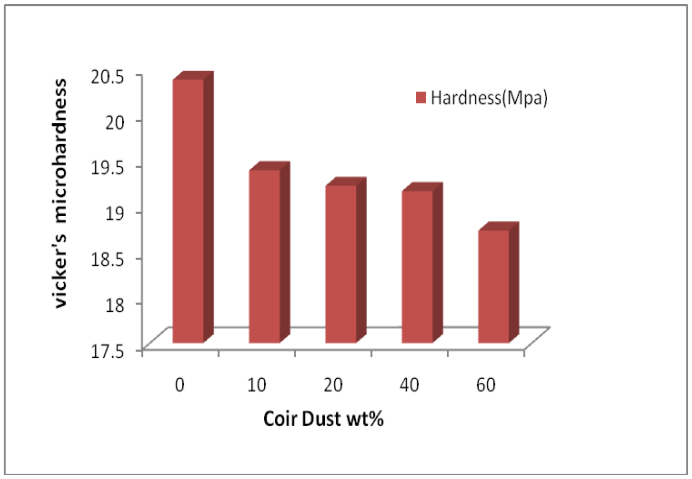


Figure 4.2 Variation of Hardness of composites with wt% of coir dust reinforced epoxy composites.

4.2.3 Flexural Strength

Figure 4.3 shows the comparison of flexural strength of the coir dust reinforced epoxy composites.There is an decrease flexural strength with increase in wt% of coir dust in composites, due to increment in the void fraction.

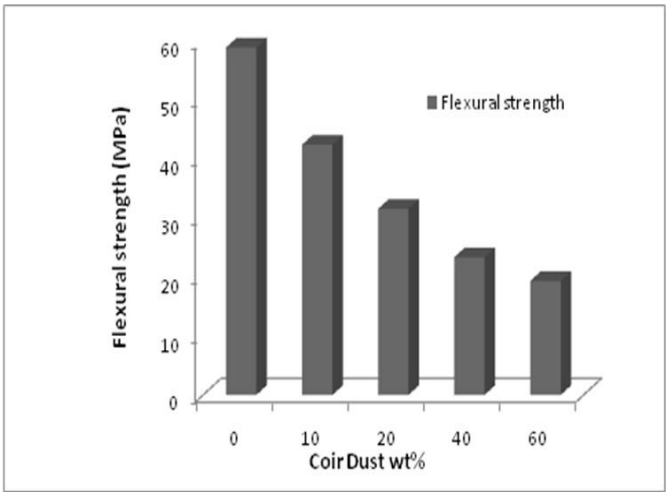


Figure 4.3. Variation of the Flexural strength of composites with wt% of coir dust reinforced epoxy composites.

From Scanning electron micrographs (SEM) of the Morphology and fracture surface of the coir dust composite (Figure 4.4), it is observed that aithough some amount of cavitation is that, but good bonding with the matrix has taken place.. The fracture surface indicates that britle type fracture failure of the composite.

(a) (b)

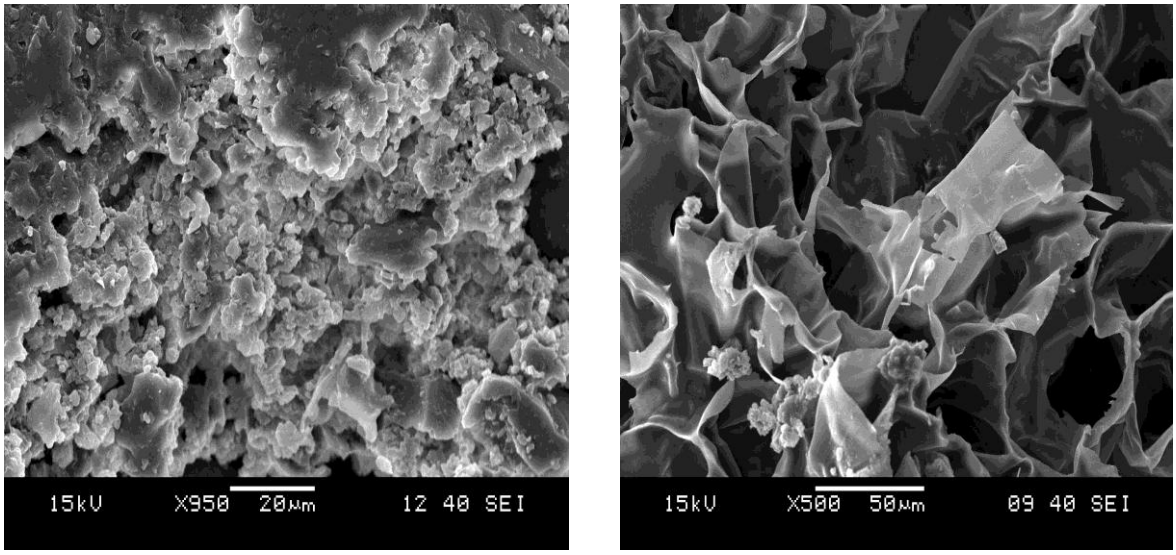


Figure 4.4**.** SEM Analysis of coir dust reinforced polymer composite (a) Morphology at 60 wt% of coir dust (b) Fracture surface of the coir dust composites at 40 wt% of coir dust.

4.3 FTIR Analysis

The content of the coir dust including moisture ,cellulose lignin, ash, and extractives.the content of lignin (35.5%) is relatively high compared to the other natural fibers, while the cellulose content (36%) is higher compared to the other fiber species e.g jute (16-22%), hardwood (19-26%) **[165]**. Figure 4.5 presents the FTIR experimental analysis of the pure coir dust and composites with different wt% of coir dust.The material coir dust has a typical lignocellulosic composition, presenting bonds at 3354 cm^{-1} assigned to O-H stretch, at 2938 cm^{-1} assigned to C-H stretch from methyl and methylene groups **[158]**.The peak 1625 cm^{-1} represents the C=O bonds on hemicellulose from carboxylate groups and at 1462 cm^{-1}

assigned to CH_2 symmetric bending peaks. The peaks for pure epoxy presenting at 1046 cm-1 assigned to C-O-C bending in benzo-ether, at 2922 cm-1 represents the C-H stretching in methyl group, at 3430-3450 cm-1 represents O-H stretching in free alchohol.The peak range about 1000cm-1 to 1200cm-1 become more wide and short in case of 10wt% of coir dust composite as compared to corresponding peaks in pure epoxy resin, due to the formation of hydrogen bonding hydrogen atom of the methyle groups in coir dust and oxygen atom of the epoxy reesin.

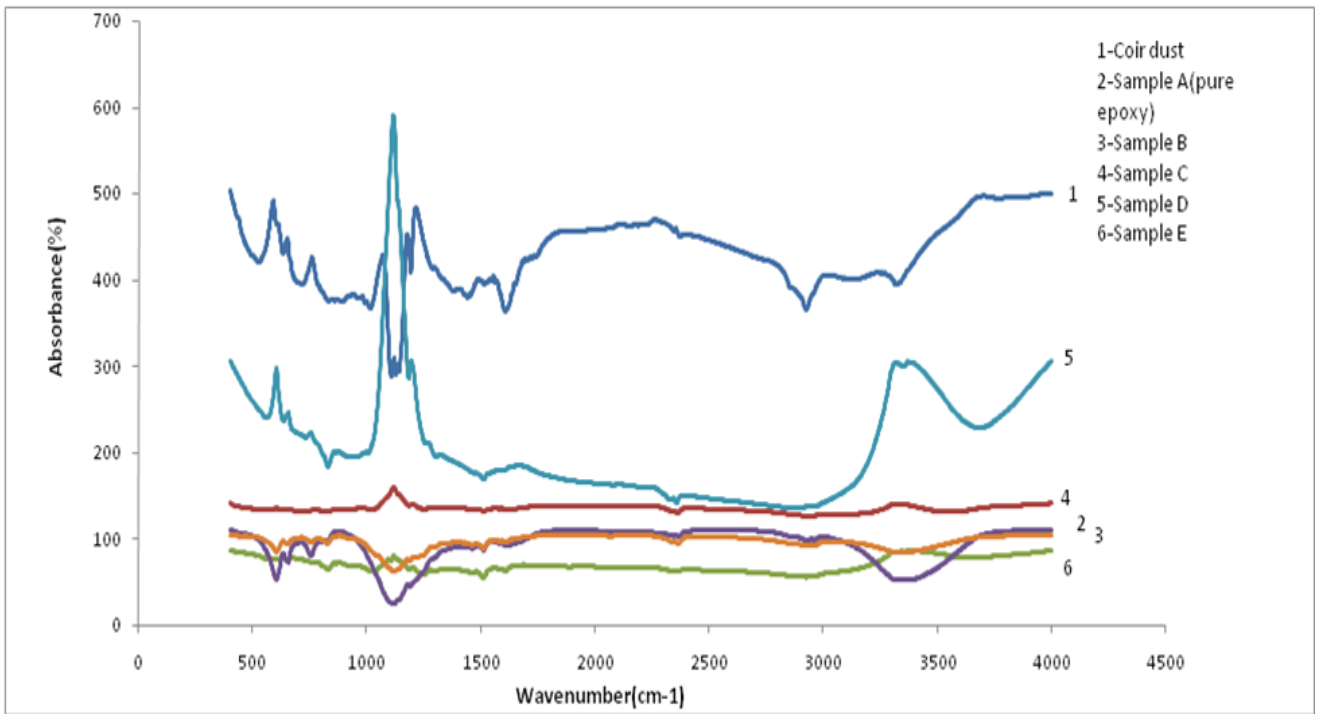


Figure 4.5: FTIR experimental analysis of pure coir dust and composites with different wt % of coir dust

4.4 Dielectric properties

Figure 4.6 gives the variation of dielectric constant, and tangent loss with frequency for different weight percentage of coir dust reinforcement at room temperature. From the figure it is clear that the K and ε" are increases with increasing coir dust content up to certain limit(i.e up to 40 wt%) due to the absorption of moisture at the fiber resin interface,as the dielectric of water is very high,with further increase in reinforce amount both K and ε" are decreases.It also be noted that with increasing the frequency the dielectric

constant was decreased ,it is the expected behaviour in most of the materials**[154]**. As frequency increases more and more of the bound charges will start to oscillate out of phase with the applied voltage and will contribute to A.C conductivity causing k decreases ,and also observed that with increasing frequency dielectric loss decreased.

(a) (b)

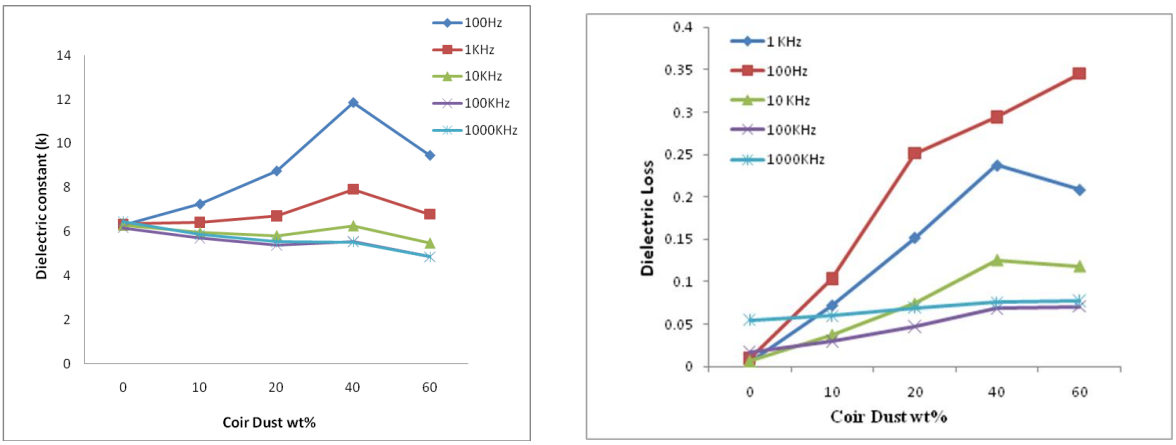
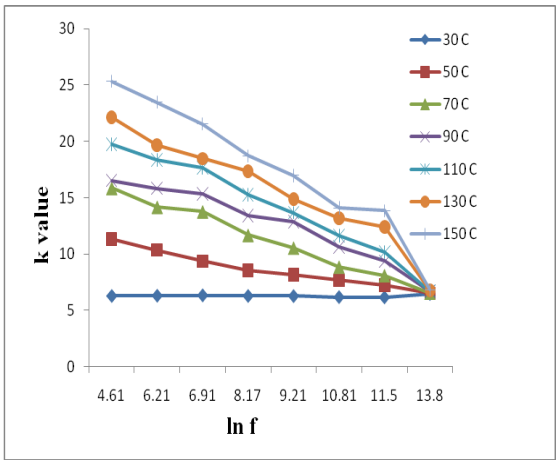


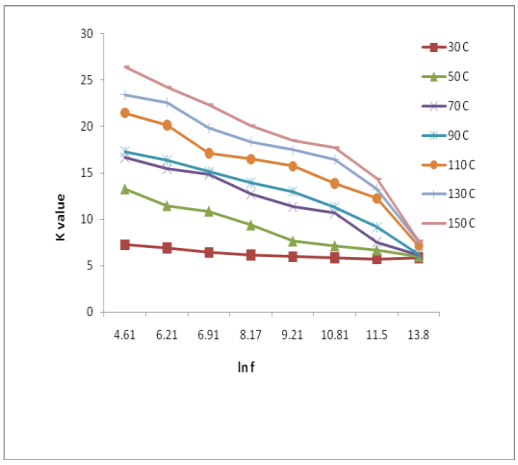
Figure 4.6. Frequency dependence of (a) Dielectric constant, (b) Dielectric loss for different wt% of coir dust in epoxy resin at room temperature.

Figure 4.7 shows the variation of dielectric constant(K) with frequency at different temperatures for samples A,B,C,D,and E, respetively.From the figures it is clear that dielectric constant decreased with increasing frequency at constant temperature, and increased with increasing temperature at constant frequency ,low frequency and high temperature have more prominent on the dielectric constant.Decreasing nature of the K value with increasing frequency is due to the dielectric relaxation which is the cause of anamalous dispersion.At higher frequencies the orientation of polar molecules along the direction of the applied electric field is disturbed**[155]**.

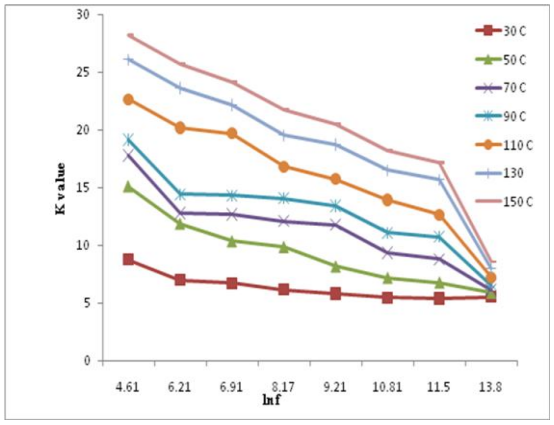
(a)



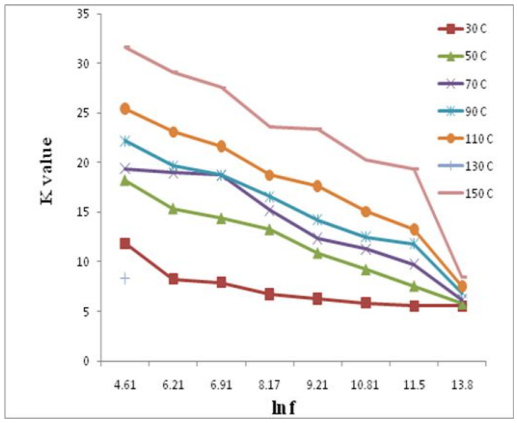
(b)



(c)



(d)



(e)

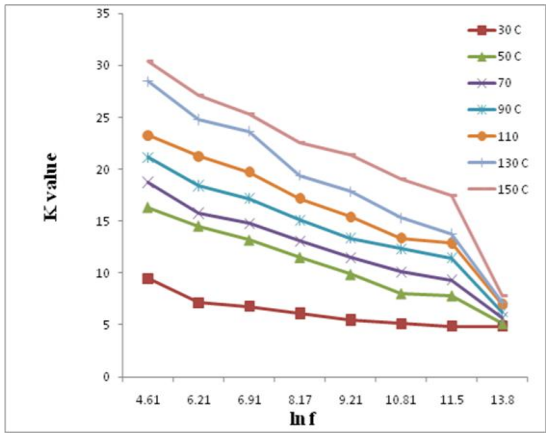
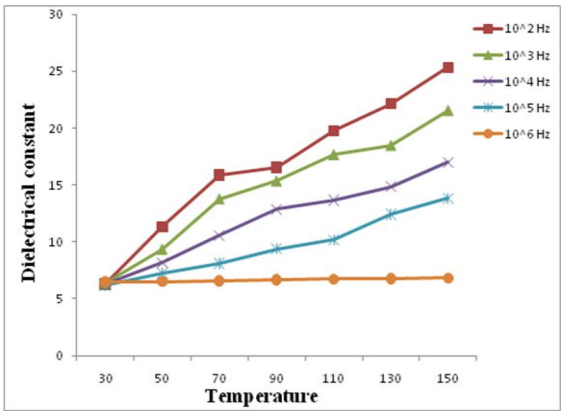


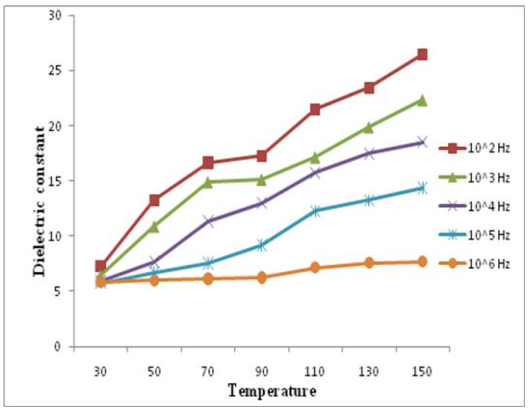
Figure 4.7. Frequency dependence of K-value at different temperatures for (a)sample A,(b)sample B, (c) sample C, (d)sample D , and (e)ample E.

Figure4.8 (a-e) shows the variation of dielectric constant with temperature at different frequencies for samples A, B, C, D, and E, respectively. From the figure it is clear that the value of K is increased with increasing temperature at constant frequency. The increase in K value with increasing temperature is due to the greater freedom of movement of dipole molecular chains. With increasing temperature the polarization increases and hence the dielectric constant is also increased **[156]**.

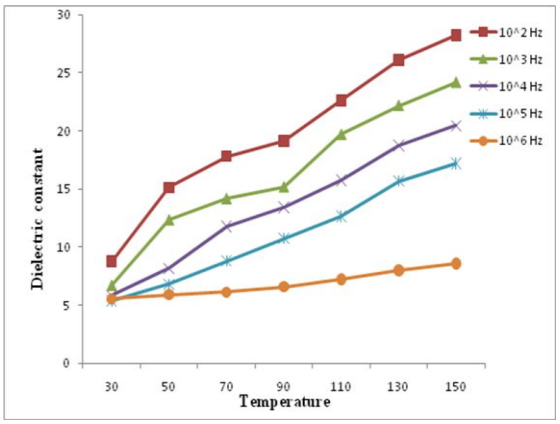
(a)



(b)



(c)



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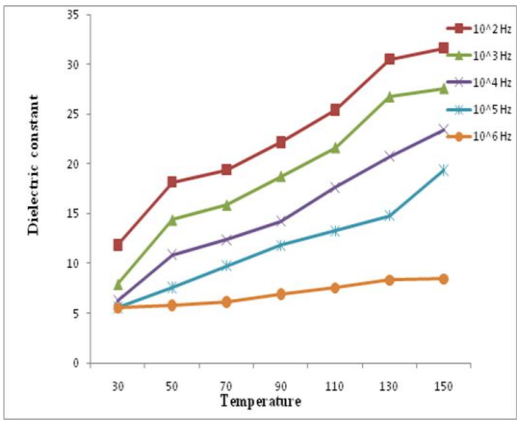

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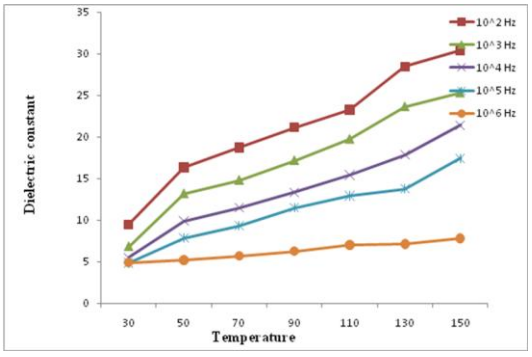
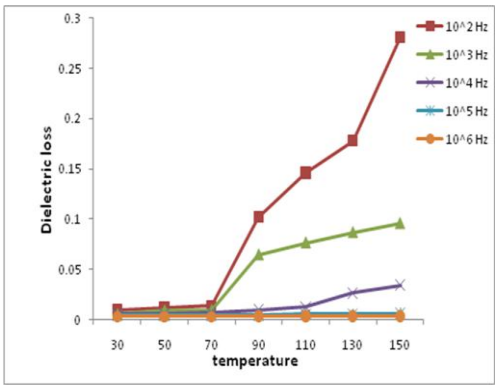


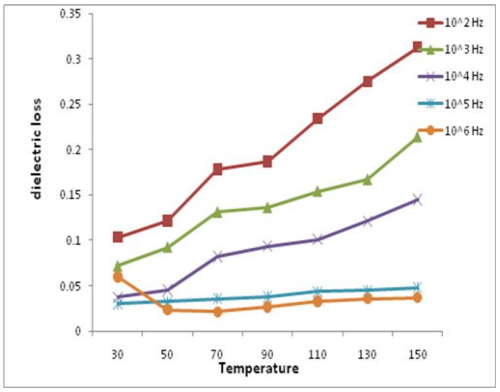
Figure 4.8.Temperature dependence of K-value at different frequencies for(a) sample A,(b) sample B, (c)sample C,(d)sample D,and(e) sample E.

Figure 4.9(a-e) shows the variation of the dielectric loss with temperature at different frequencies for samples A,B,C,D,and E respectively. From the figure it is clear that dielectric loss is highly increases with increasing temperature at lower frequencies ,at higher frequencies the increment in the dielectric loss is negligible.

(a)



(b)



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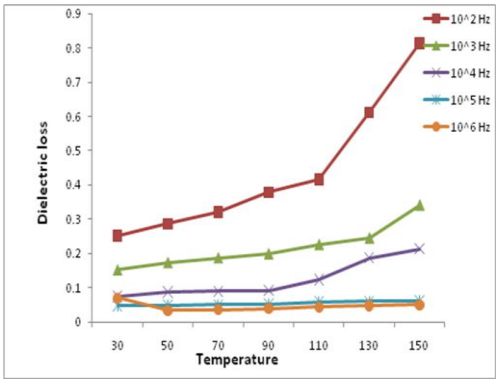

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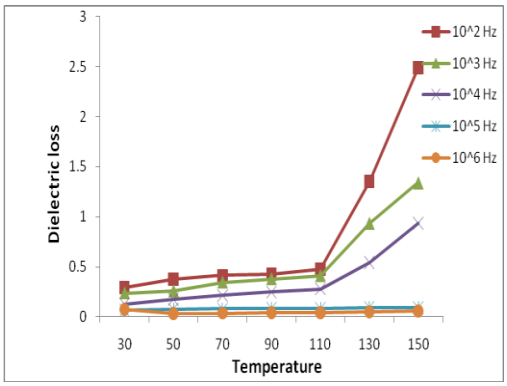

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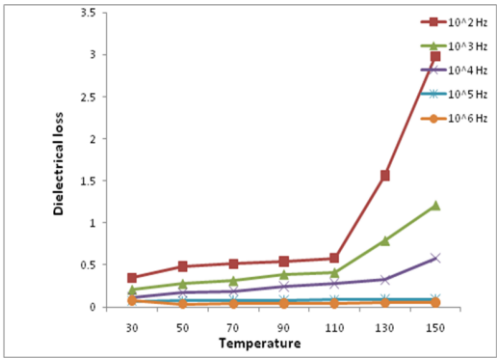
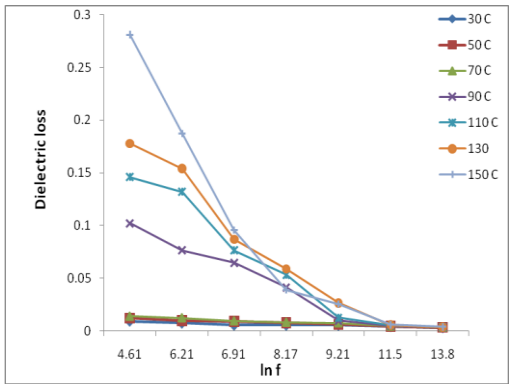


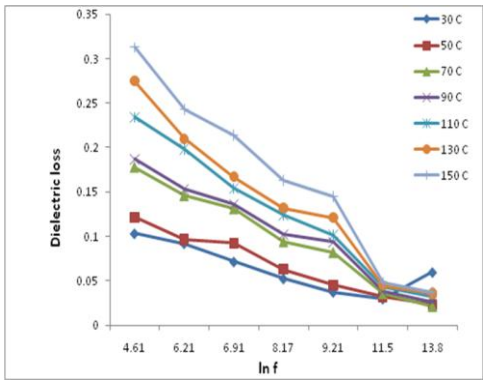
Figure 4.9.Temperature dependence of loss factor at different frequencies for(a)sample A,(b)sample B, (c)sample C,(d)sample D,and (e)sample E.

Figure 4.10(a-e) shows the variation of dielectric loss with frequency at different temperatures for samples A,B,C,D,and E, respectively.From the figure it is clear that the loss factor decreased with increasing frequency at constant temperature, the decrement in the loss factor for high temperature at low frequency is more prominent, it is usual behavior of most materials**[157]**.

(a)



(b)



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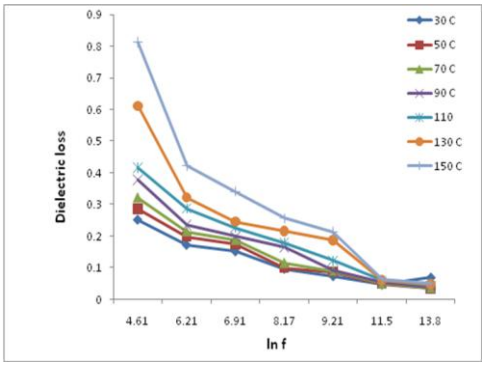

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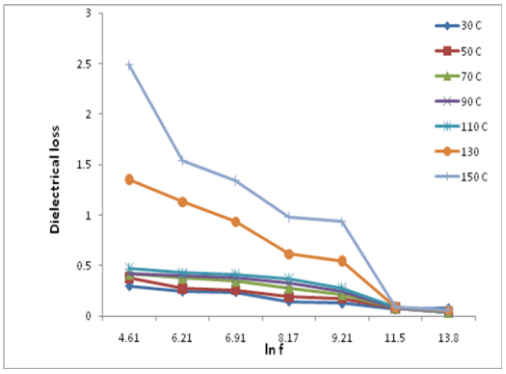


(e)

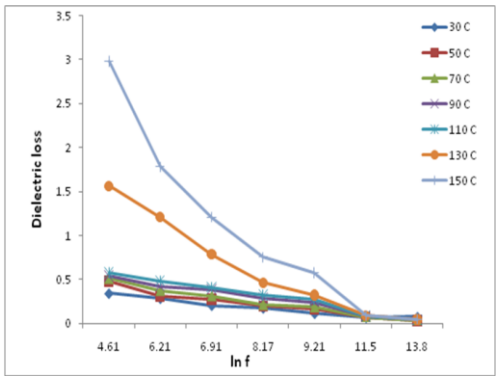


Figure 4.10. Frequency dependence of loss factor at different temperatures for(a) sample A, (b)sample B, (c)sample C,(d) sample D, and (e) sample E.

Figure 4.11(a-b) shows the variation of conductivity and resistivity with frequency at different wt% percentage of coir dust. From the figure it is clear that the conductivity of the material is increased with increasing frequency at room temperature, it is also observed that at 40 wt% coir dust the A.C conductivity is more pronounced. The resistivity of the material is decreased with increasing frequency at room temperature, the decrement of A.C resistivity at 40 wt% coir dust is more pronounced.

(a) (b)

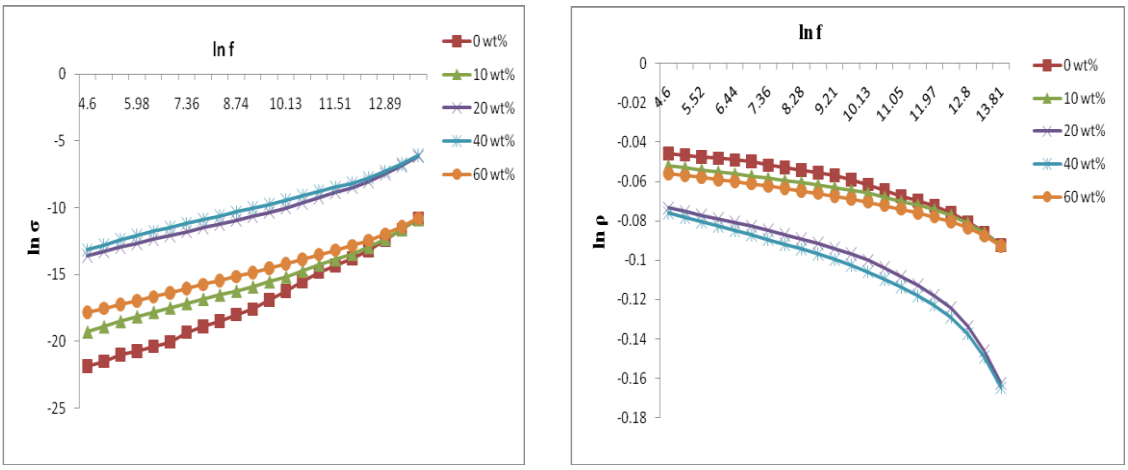


Figure 4.11. Frequency dependence of (a)conductivity and (b)resistivity

Figure 4.12 shows the variation of the A.C conductance with frequency and temperature for different samples. With increasing the frequency and temperature the conductance of the

material increases due to the oscillation of the dipolar molecules in out of phase with the applied field and random movement of the dipolar molicules.

(a) (b)

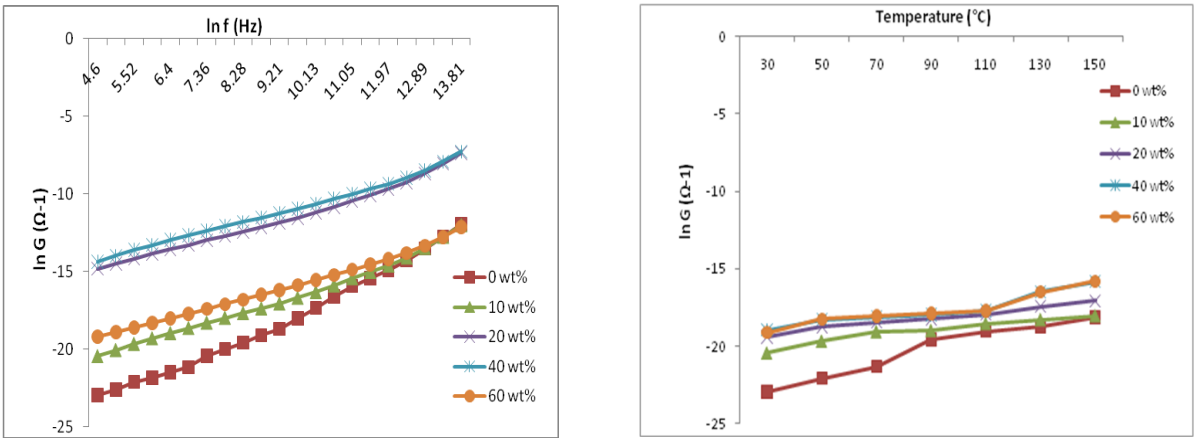


Figure 4.12. Variation of A.C Conductance with (a) Frequency (b) Temperature for different wt% of coir dust in epoxy resin.

Figure 4.13 gives the variation of the A.C Resistance with frequency of applied electric field and testing temperature for different samples.It is observed that with increasing frequency and temperature the A.C resistance decreases due to increament in the conductivity.

(a) (b)

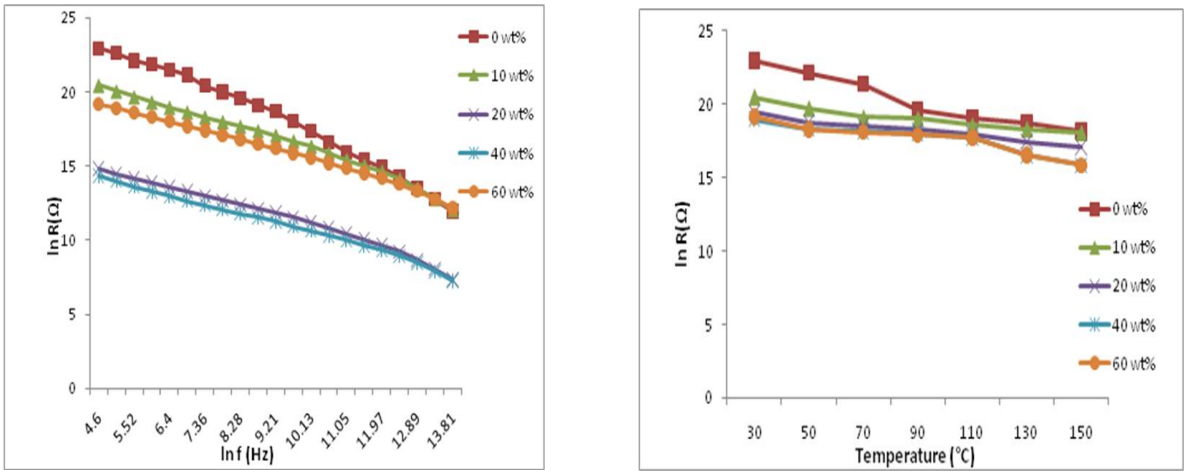


Figure 4.13. Variation of A.C Resistence with (a) Frequency (b) Temperature for different wt% of coir dust in epoxy resin.

4.5 Study of abrasion wear behavior

Fig.4.14 gives the effect of fiber content on the specific wear rate(SWR), from the figure it is clear that with increasing fiber content specific wear rate is decreases. It means that coir dust fiber is very effective in improving the tribological performance of epoxy, especially for its wear resistance. The main reason for decrease the wear rate ,at higher coir dust loading, wear mechanism was dominated by coir dust,which is less brittle than the epoxy resin matrix.

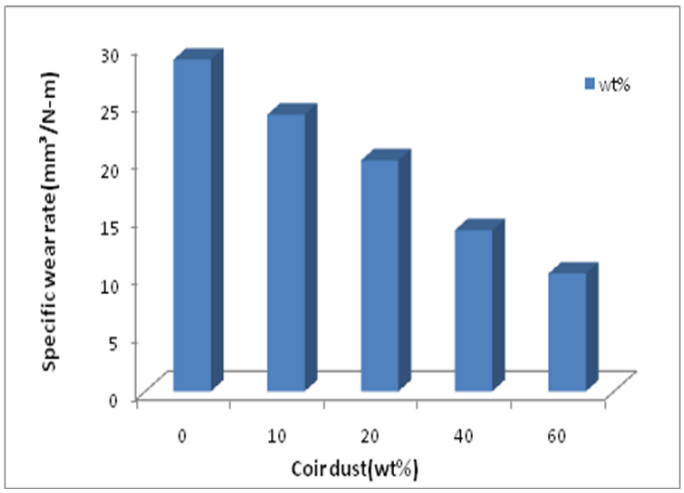
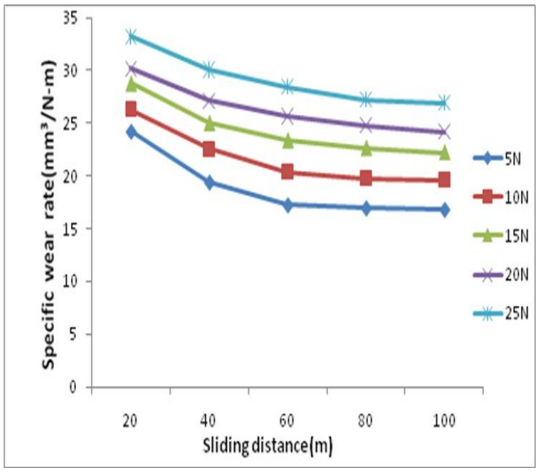


Fig .4.14 Variation of Specific wear rate with fiber content

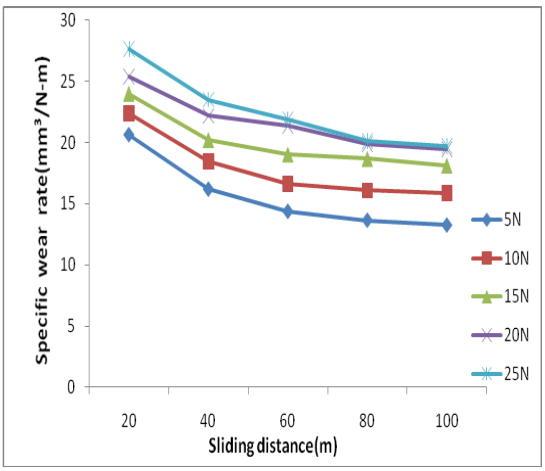
Fig.4.15 shows the plot for for specific wear rate as a function of sliding distance for different composites at different normal loads.The SWR decreased with increase of sliding distance for all the samples.Also initially high wear SWR observed because the abrasive paper was fresh.With consecutive runs,wear loss decreased gradually,because the abrasive grits became less effective.The wear debris filled the space between the abrasives(SiC grits), which reduced the depth of penetration in the sample.In other words,contact stress was reduced when debris came between the surfaces.

Fig.4.16 shows the plot for SWR as a function of normal loads for unreinforced and reinforced composites at different sliding distances(at the sliding velocity of 0.540 m/sec). The SWR increases with increasing of normal load.The SWR was relatively low at lower load because of less penetration and less number of abrasive particles were in action with sliding surface. The SWR was increased with increasing load because most of the abrasive particles were in action with the sliding surface and created more grooves, resulting high material was removed from the surface.

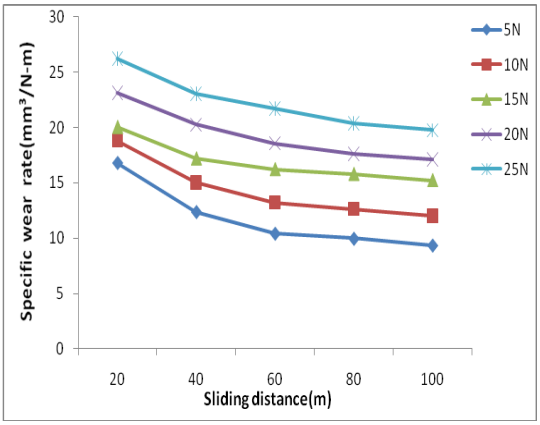
(a)



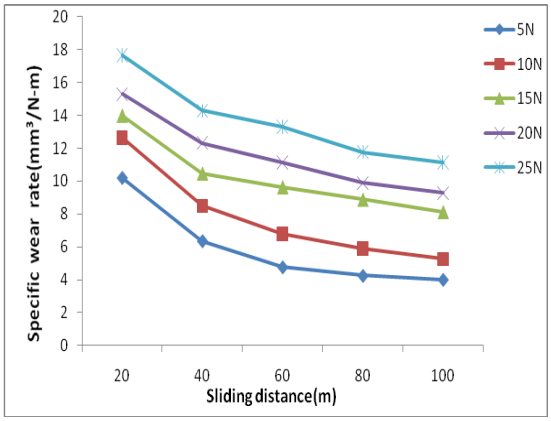
(b)



(c)



(d)



(e)

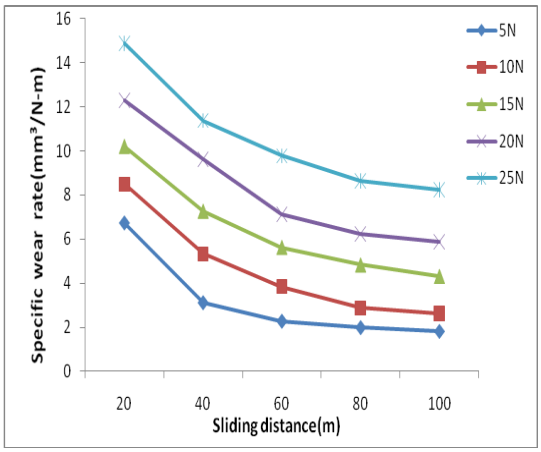
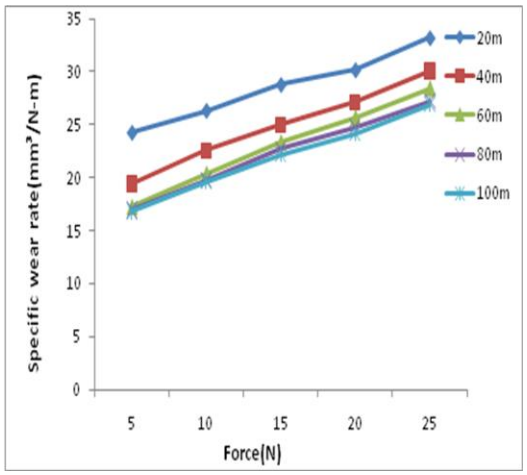
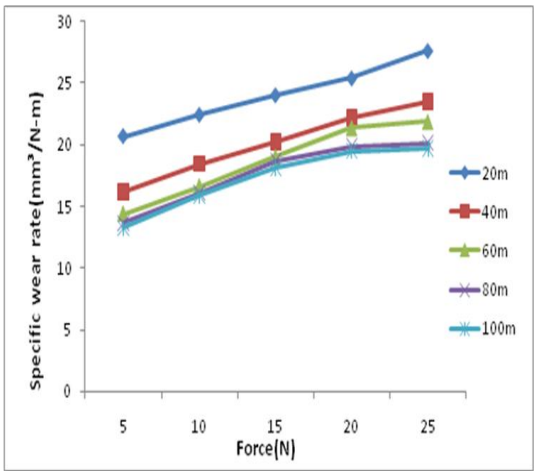


Fig.4.15. Sliding distance dependence of Specific wear rate at different normal loads for (a)sample A,(b)sample B, (c) sample C, (d)sample D, and (e)sample E.

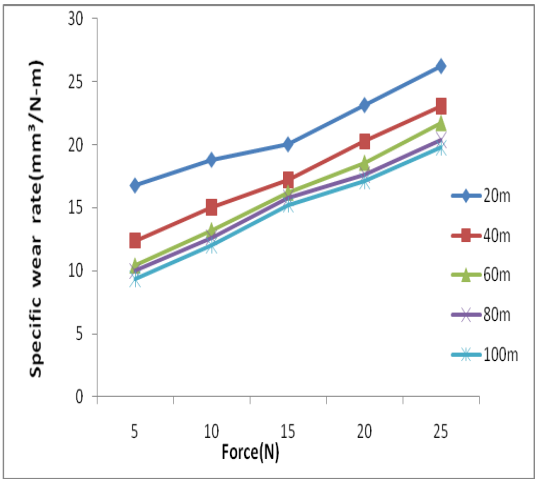
(a)



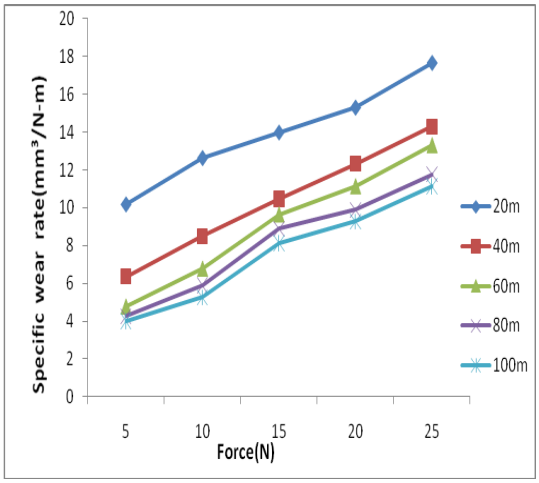
(b)



(c)



(d)



(e)

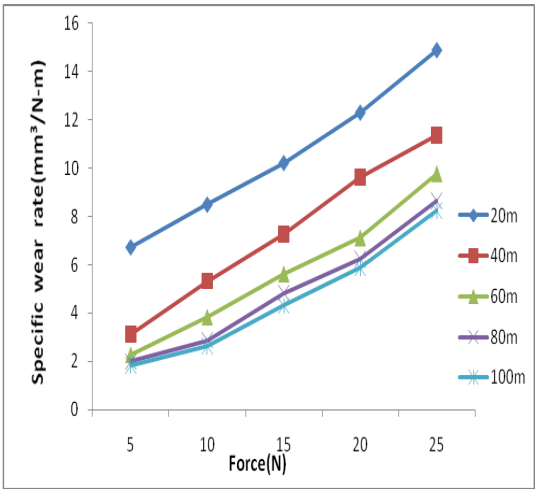
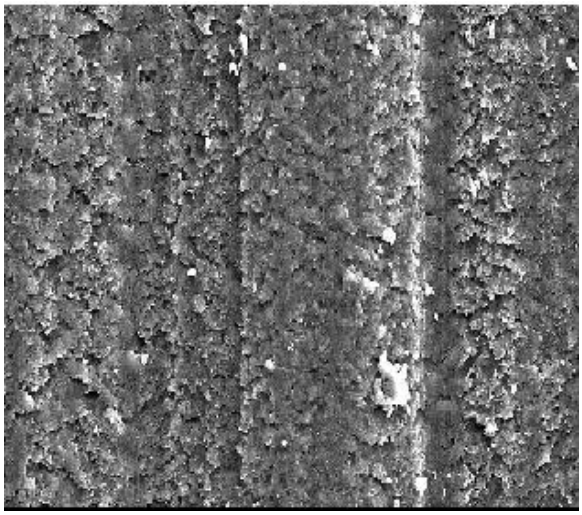


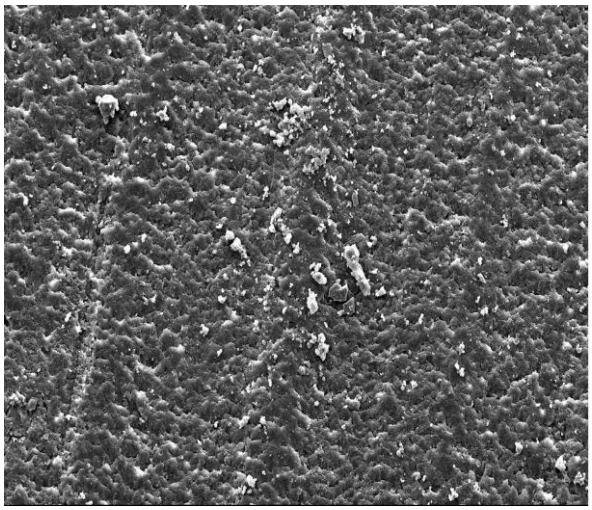
Fig.4.16 Normal load dependence of Specific wear rate at different Sliding distances for (a)sample A,(b)sample B, (c)sample C, (d)sample D, and (e) sample E.

Figure 4.17(a),(b),and(c) shows the worn surface morphologies of pure epoxy ,10wt%,and 40wt% of coir dust composites after 100m sliding distance(sliding velosity 0.540 m/sec, 400 μm grit size ,and load at 20N).Wear tracks are formed during multi pass wear due to micro-cutting. It is clear from the microstructures ,initially micro- cracs are formed around the coir dust paricles, and particles were removed under compression and shear. Increase of the coir dust content increased the resistance to shear force, this is may be due to its honeycomb like structure of the mesocarp.

(a)



(b)



(c)

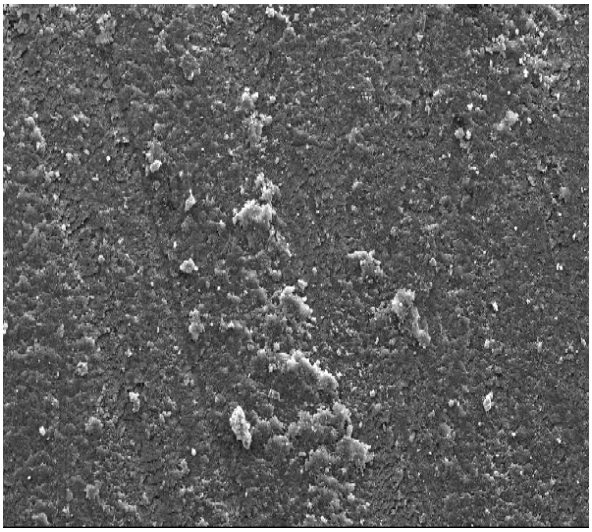


Fig.4.17 Scanning electron micrograph of (a) worn surface of pure epoxy , (b) worn surface of 10 wt% coir dust reinforced composite,and (c) worn surface of 40 wt% coir dust reinforced composite under 20 N normal load against 400μm grit size abrasive paper.

4.6 Study of Erosion wear behavior

Figure 4.18 shows that the variation of the erosion wear rate by varying the coir dust content.From the figure it was clear that with increasing the coir dust erosion rate decreases, this is beacuse with increasing coir dust content fiber-matrix interfacial bonding increases and erosive mechanism dominated by the fiber content which is soft compare with the matrix material.

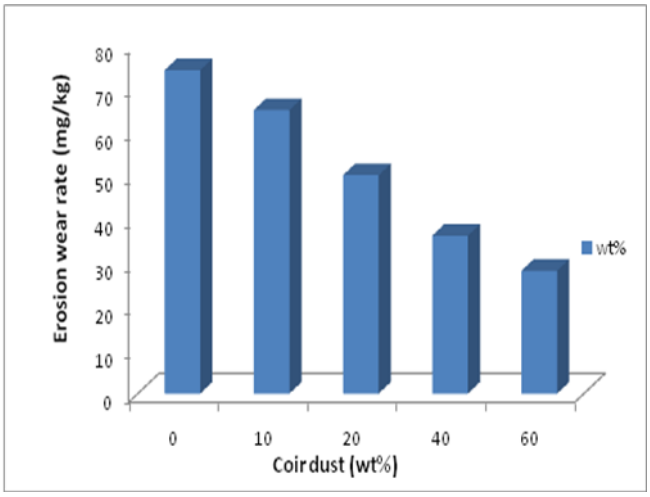
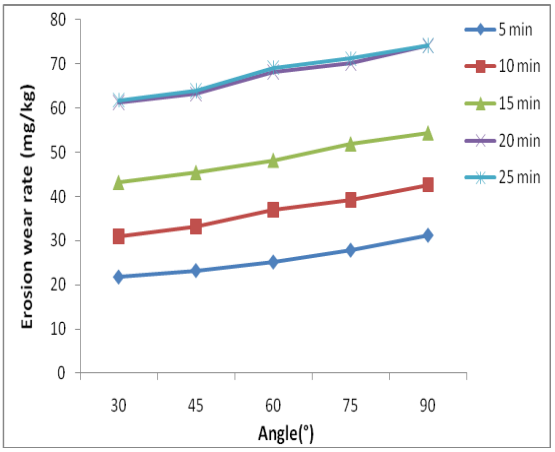


Figure 4.18: Coir dust content dependence of the erosion wear rate.

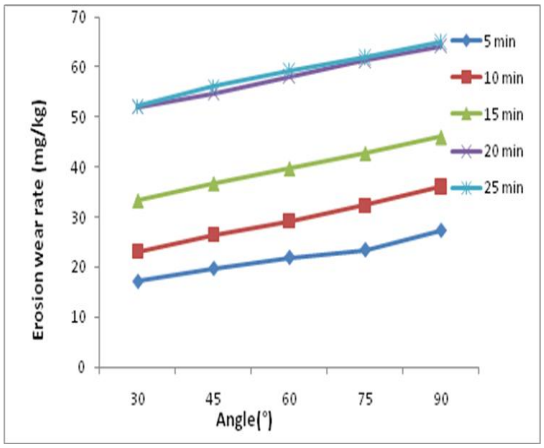
Generally erosion behaviour of the composites depends on the impingement angle. Brittle behavoiur is characterized by maximum erosion rate at normal incidence (90°), and the ductile behaviour is characterized by the maximum erosion wear rate at 15-30° impingement angle. Figure 4.19 shows the Impingement angle dependence of erosion wear rate at different time intervals for all samples. From the figure it was clear that with increasing the impingement angle erosion rate of the composite is increased, and attains a peak value at impinge angle 90°, it means that the material shows the brittle type failure.

Figure 4.20 shows Impact velocity dependence of erosion wear rate at different time intervals for (a)sample A,(b)sample B, (c) sample C, (d)sample D, and (e)sample E. From the graphs we can observe that with increasing impact velocity erosion rate of the composite is increasing. This is because; with increasing erodent particle velocity the tangential component of the impact force which is cause for the erosion increases and material fails/erodes.

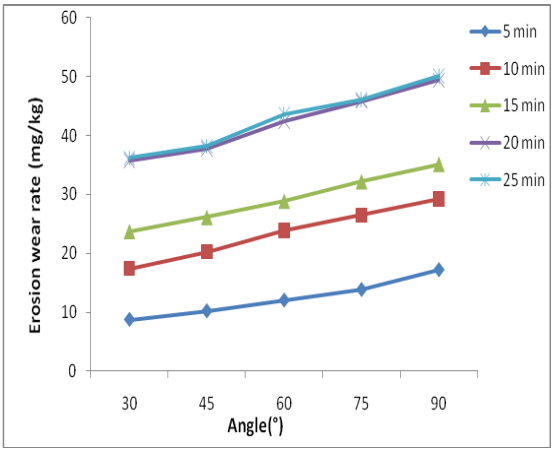
(a)



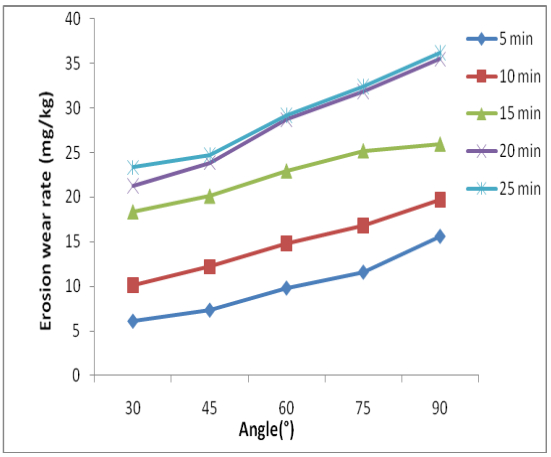
(b)



(c)



(d)



(e)

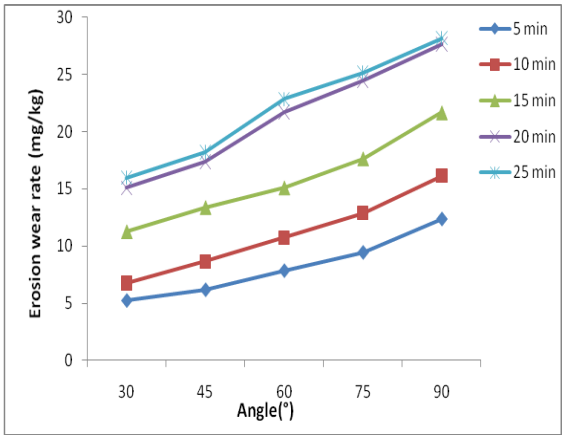
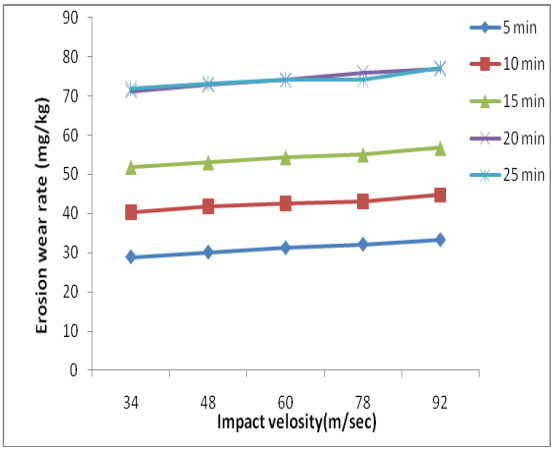
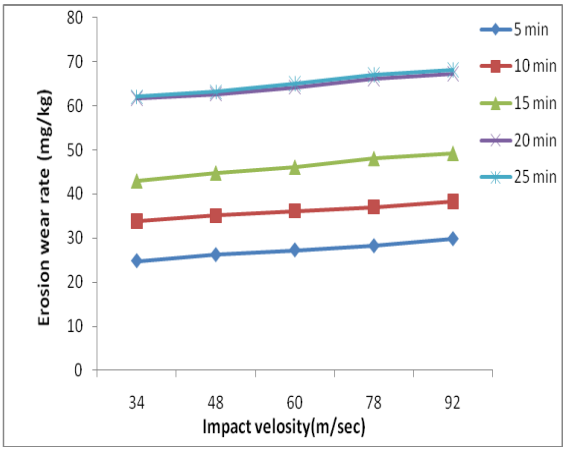


Figure 4.19: Impingement angle dependence of erosion wear rate at different time intervals for (a)sample A,(b)sample B, (c) sample C, (d)sample D, and (e)sample E.

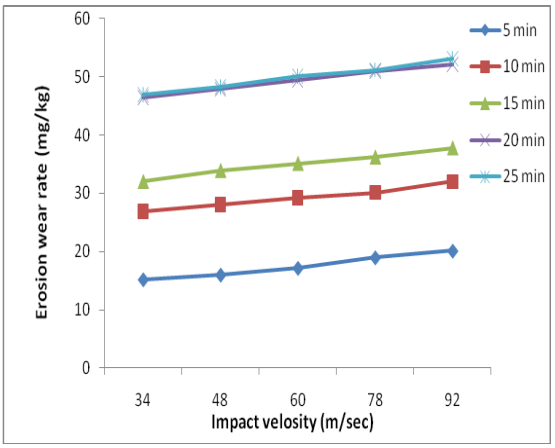
(a)


Erosion wear rate (mg/kg)
90
80
70
60
50
40
30
20
10
0
34
48
60
78
92
Impact velosity(m/sec)
5 min
10 min
15 min
20 min
25 min

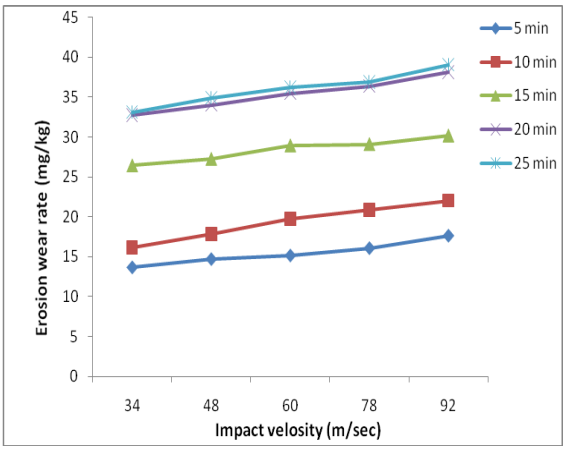
(b)


Erosion wear rate (mg/kg)
80
70
60
50
40
30
20
10
0
34
48
60
78
92
Impact velosity(m/sec)
5 min
10 min
15 min
20 min
25 min

(c)


Erosion wear rate (mg/kg)
60
50
40
30
20
10
0
34
48
60
78
92
Impact velosity (m/sec)
5 min
10 min
15 min
20 min
25 min

(d)


Erosion wear rate (mg/kg)
45
40
35
30
25
20
15
10
5
0
34
48
60
78
92
Impact velosity (m/sec)
5 min
10 min
15 min
20 min
25 min

(e)

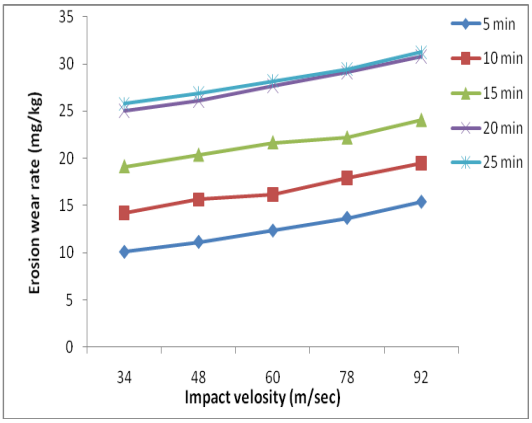
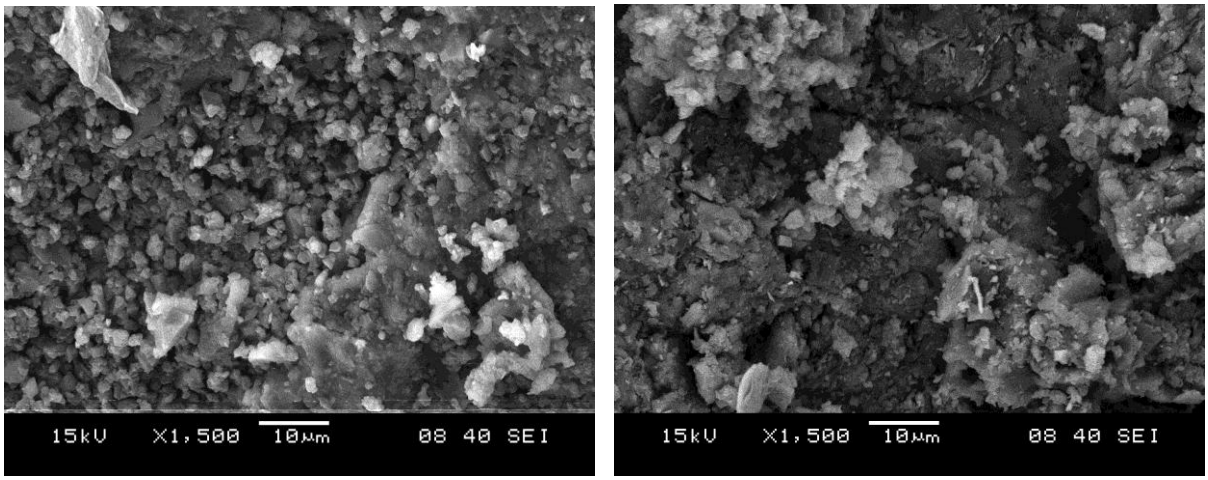

Erosion wear rate (mg/kg)
35
30
25
20
15
10
5
0
34
48
60
78
92
Impact velosity (m/sec)
5 min
10 min
15 min
20 min
25 min

Figure 4.20: Impact velocity dependence of erosion wear rate at different time intervals for (a)sample A,(b)sample B, (c) sample C, (d)sample D, and (e)sample E.

Figure 4.21 shows the SEM micro graphs of of surfaces eroded (a) at 30° (b) at 60° ,and (c) at 90° impingement angle for sample C with impact velocity 48 m/sec.From figure 4.21(a) we can observe that the intensive debonding of the composite due to the breakage of the fibers,figure 4.21(b) shows the increament in the pulverization process with increasing the impingement angle , leading to the higher erosive wear of the composite material.Figure 4.21(c) shows the brittle fracture of the composite.As the impingement angle increased, the extent of fiber damage (initiated at fiber-matrix debonding followed by the microcracking ,microcutting, pulverization ,and removal from the surface leaving behind weakened surface of cavity of appropriate size) also increased.

(a) (b)



(c)

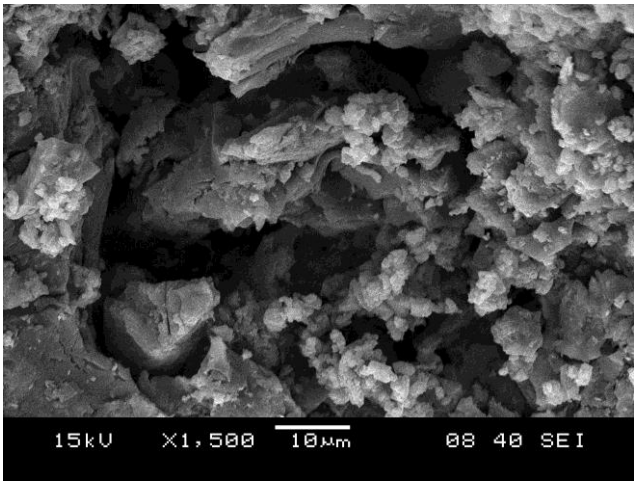


Figure 4.21: Scanning electron microscope microphoto of surfaces eroded (a) at 30° (b) at 60° ,and (c) at 90° impingement angle for sample C with impact velocity 48 m/sec.

4.7 Effect of chemical treatment on the properties of composite

Changes in the chemical nature of the lignocelluloses and hemicellulose are expected to occur upon chemical treatment. These possible modifications were studied by infrared spectroscopy, as presented in Figure 4.22.The material coir dust has a typical lignocellulosic composition, presenting bonds at 3354 cm^{-1} assigned to O-H stretch, at 2938 cm^{-1} assigned to C-H stretch from methyl and methylene groups **[158].**The peak 1625 cm^{-1} represents the C=O bonds on hemicellulose from carboxylate groups and at 1462 cm^{-1} assigned to CH_2 symmetric bending peaks **[158, 159]**.

Sample treated with NaOH is not presenting the peaks 3354 cm^{-1},2938 cm^{-1} and 1625 cm^{-1}. The removal of lignin and hemicellulose from the coir dust surface causes these peaks to dissapear**[160,159]**. The peak 1620 cm^{-1} is present in KOH treated sample indicates the presents of hemicellulose content and the dissaperence of peak 2938 cm-1 and presents of 3354 cm^{-1}, indicates that partially removal of the lignin content . The peaks 3354 cm^{-1} and 2938 cm^{-1} are not present in the HCl treated sample. The removal of lignin from the coir dust surface causes these peaks to dissapear. The peak 1658 in case of HCl treated coir dust, indicats the presence of hemicellulose content.

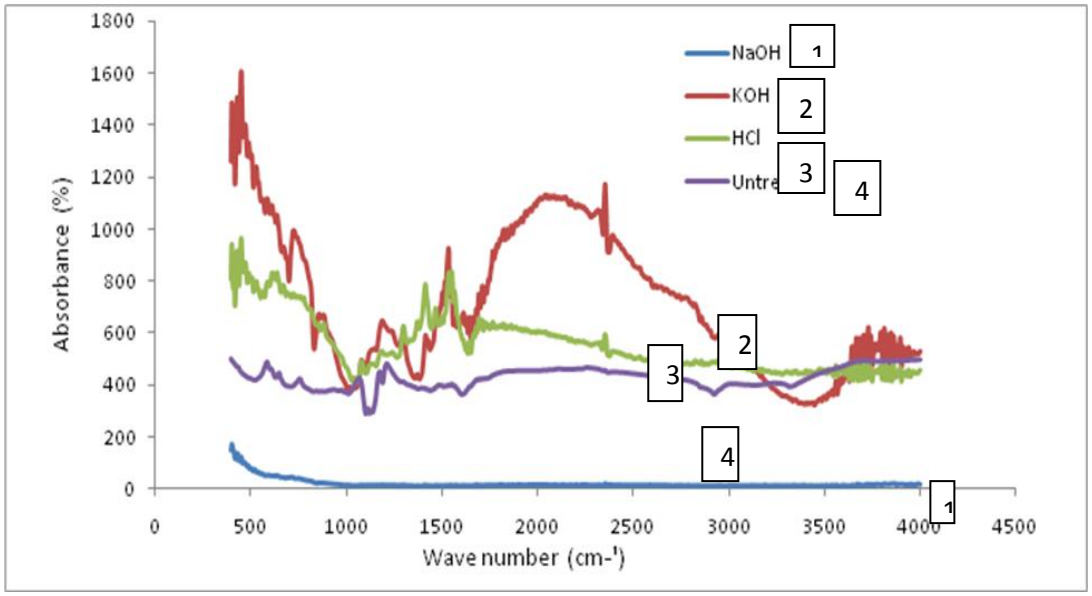


Figure 4.22: FTIR experimental analysis of treated and untreated coir dust

4.7.1 Effect of the Chemical Treatment on Mechanical Properties

Constituent like hemicellulose was hydrolyzed by the action of alkaline solutions whereas lignin was removed during additional steps using sodiumchloride or hydrogen peroxide. The bonding nature between fiber and the matrix depends on the atomic arrangement, chemical properties of the fiber and the constitution of the polymer matrix. However, in the natural fiber composite, cellulose is the principle coupling agent in the polymer/fiber bonding. On the other hand, lignin acts an abstruction to the coupling agent diffusion, preventing good adhesion**[161].**

The results of the hardness and flexural strength properties obtained are shown in Figure 4.23. The results revealed the response of the composite to the hardness and flexural strength tests. It is observed that, sample treated with NaOH has highest hardness and flexural strength(19.8 Hv &33.13 MPa) followed by sample treated with HCl and KOH. This is due to the imprvement in the adhesion between the interface of coir dust particle and polymer matrix.

(a) (b)

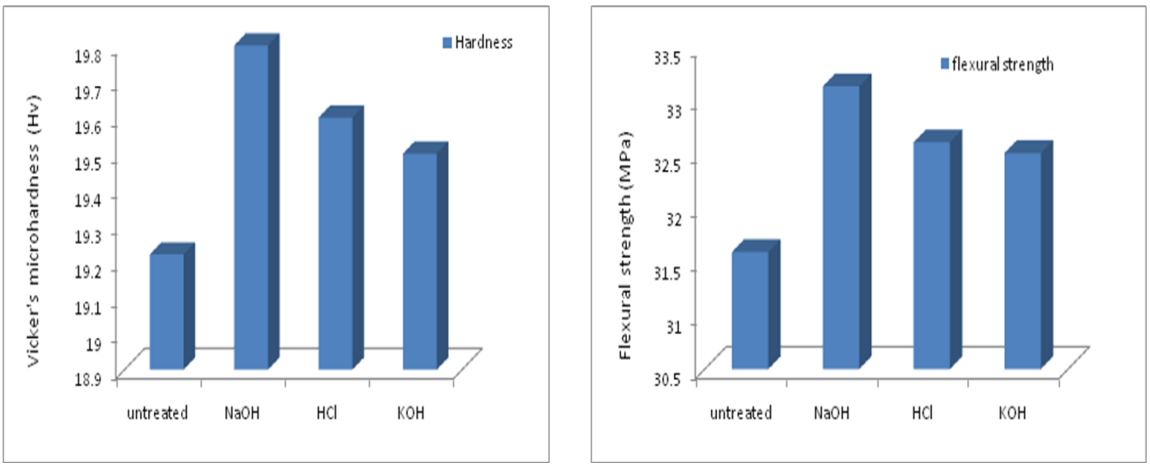


Figure 4.23: Variation of the(a) hardness and (b) flexural strength on chemical treatment

4.7.2 Effect of the Chemical Treatment on Abrasive Wear properties of the coir dust composites

The specific wear rate of the untreated and treated coir dust composites are presented in Figure 4.24. Meanwhile, NaOH treated coir dust composite showed lower specific wear rate compared to untreated, HCl and KOH treated composites. The reduction in the SWR is caused by the strong adhesion between the fibers and matrix which helped to protect the rubbing surface from worn. Besides, no cracks are observed around the embedded coir dust, and this minimized the weight loss for the alkali treated coir dust composites, consequently lower SWR.

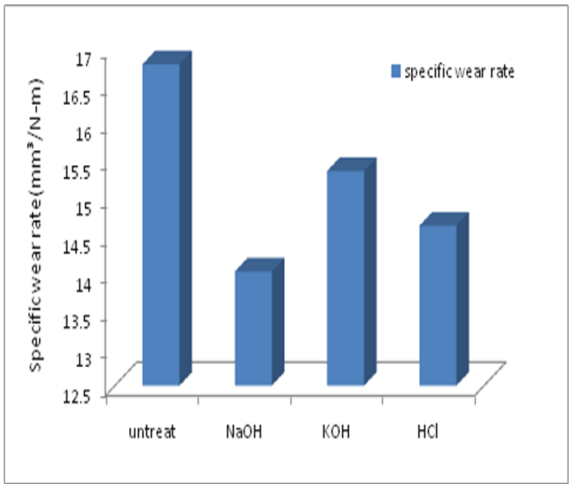


Figure 4.24: Variation of the specific wear rate on chemical treatment

Figure 4.25 presents the SWR of treated and untreated coir dust composites as a function of sliding distance for different applied normal loads. The NaOH treated composite exhibited lower specific wear rate compared to composites made with other treatments. Probable, the removal of the waxy layer by NaOH treatment has increased the mechanical interlocking between the coir dust particles and epoxy resin. The alkaline surface treatment of the coir dust enhance the interfacial bonding and strength of the coir dust. In contrast, for the untreated coir dust composite higher SWR occured. The debonded coir dust particles attributed to high friction and wear since coir dust do not play its role to protect the rubbing surface**[162].**

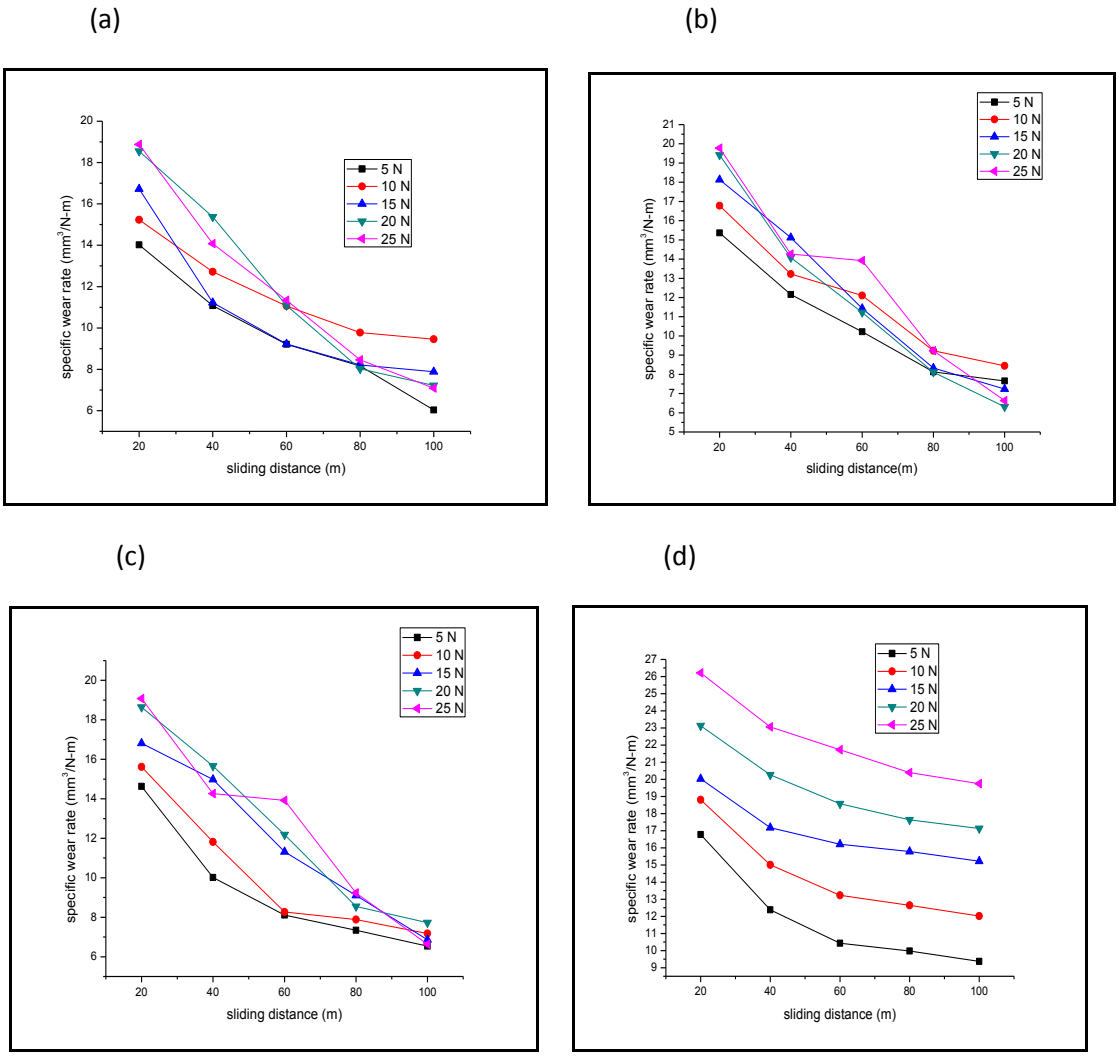


Figure 4.25: Sliding distance dependence of Specific wear rate at different normal loads for (a) NaOH, (b) KOH, (c) HCl treated and (d) untreated coir dust (20 wt %) filled polymer composite.

Figure 4.26 presents the SWR of treated and untreated coir dust composites as a function of applied normal load for different sliding distances. The nature of the SWR with normal load for untreated and treated samples is same i.e. it increases with increasing of normal load. The SWR is relatively low at lower load, partly because of less penetration and less number of abrasive particles were in action with sliding surface.

The SWR was increased with increasing load because most of the abrasive particles were in action with the sliding surface and created more grooves resulting high amount of material removal from the surface.

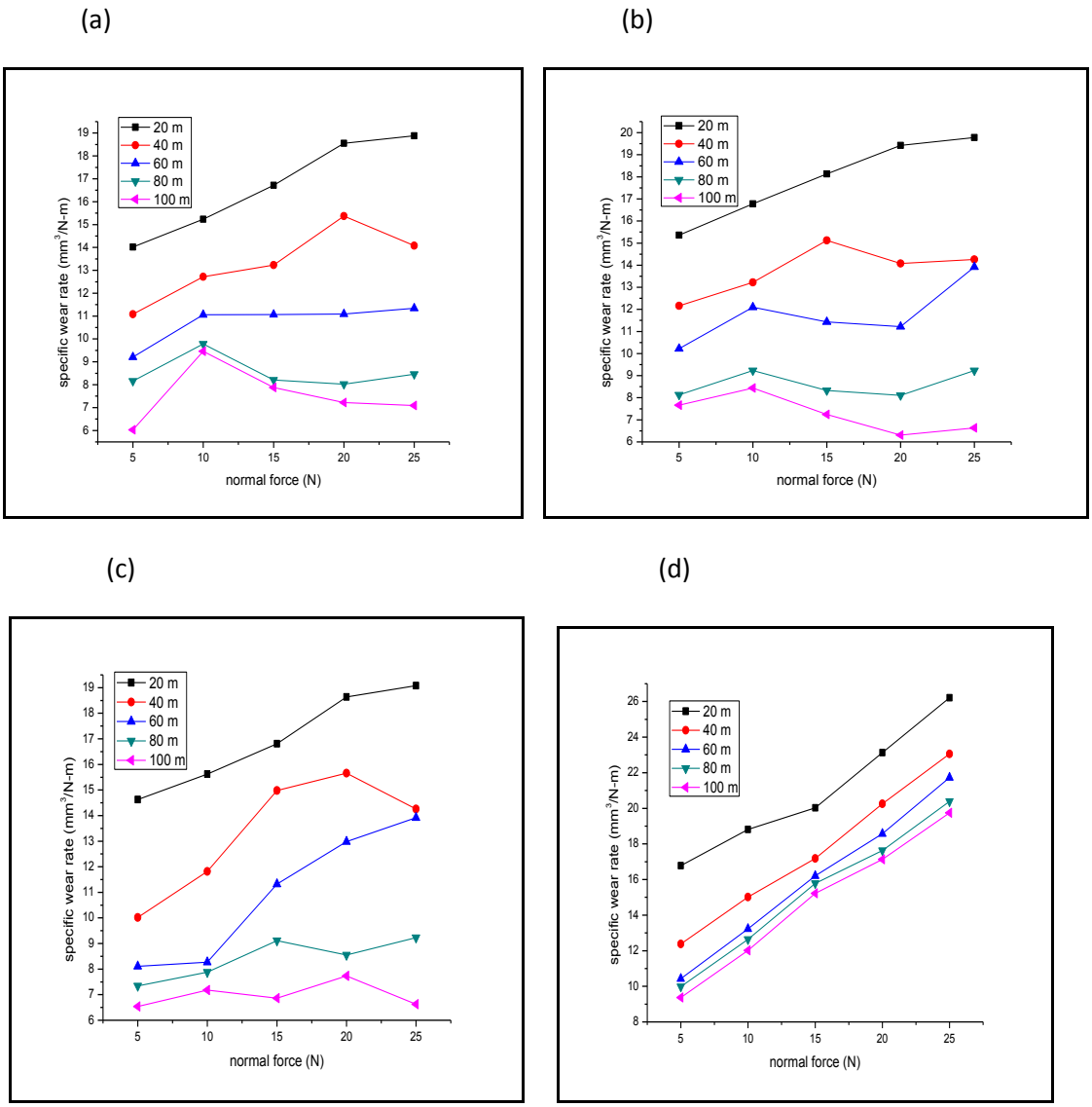


Figure 4.26: Normal load dependence of Specific wear rate at different Sliding distance for (a) NaOH, (b) KOH, (c) HCl treated and (d)untreated coir dust (20 wt%)filled polymer composite.

The effect of sliding distance on the friction coefficient of untreated and treated coir dust composites is shown in the Figure 4.27. The alkaline treated samples have low friction coefficient compare with the untreated composite.The alkaline treated composite also exhibit steady friction coefficient than the untreated composite may be due to formation of wear debris on the rubbing surface.

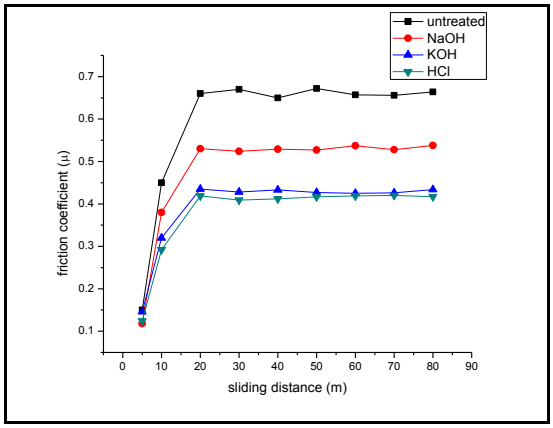
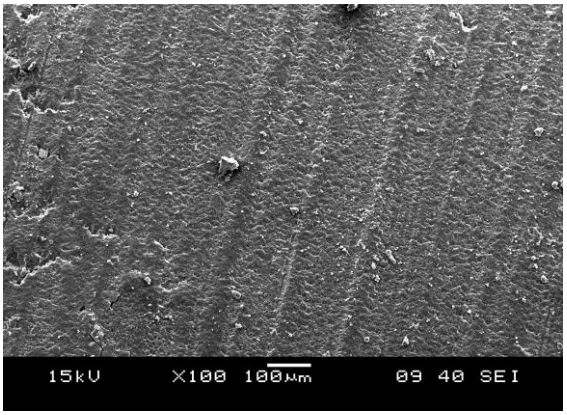


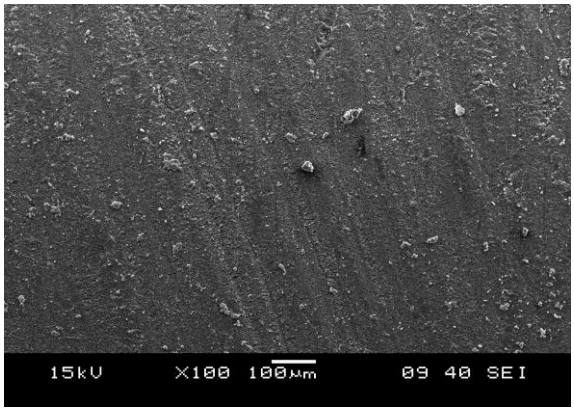
Figure 4.27: Variation of the friction coefficient with sliding distance on chemical treatment.

The worn surface of chemical treated coir dust composite tested at 20 N normal loads, 0.54 m/sec sliding velocity after 60 m sliding distance is shown in Figure 4.28. Wear tracks are formed during multi pass wear. The NaOH and HCl treated coir dust composite samples were well adhered compare the KOH treated composite at 20 N normal load and after 60m sliding distance. Some wear debris are distributed on the rubbing surface.

(a)



(b)



(c)

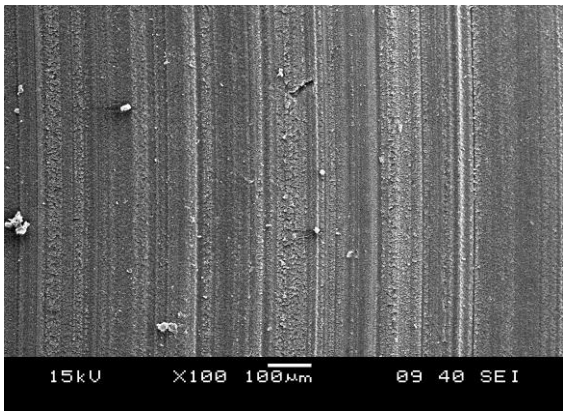


Figure 4.28: SEM micrograph of the worn surface of (a) KOH, (b) HCl, and (c) NaOH treated composite after testing at 20 N normal loads, 0.54 m/sec sliding velocity after 60 m sliding distance.

4.7.3 Effect of the Chemical Treatment on Dielectrical Properties

Dielectric constant of untreated and treated coir dust filled composite is shown in the Figure 4.29. It is observed that the treated samples are having the lower dielectric constant compare with the untreated composite. The main reason for this is decrement of the orientation polarization due to the less interaction between the water molecules and polar –OH groups of coir dust. Due to this chemical treatment of coir dust, hydrophobic nature of coir dust increases, causing reduction of the moisture absorption **[163, 164].**

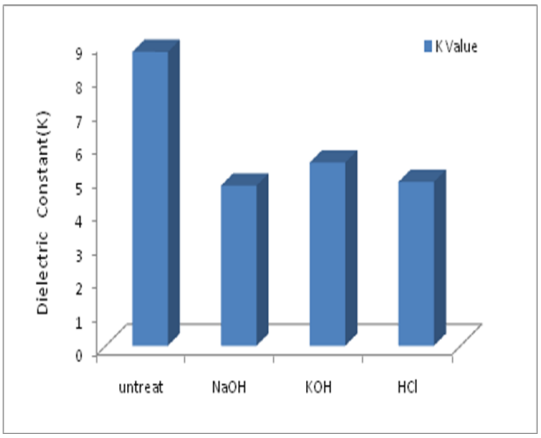


Figure 4.29: Variation of the dielectric constant of treated and untreated coir dust filled polymer composite.

Variation of the dielectric constant as a function of frequency for untreated and treated composite samples is shown in the Figure 4.30. The NaOH treated sample having the low dielectric constant compare with the untreated and other treated samples.

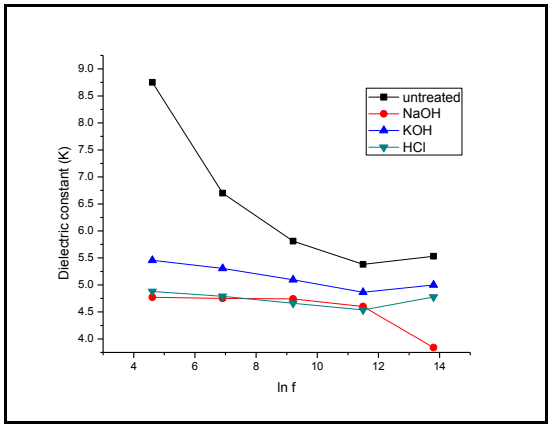
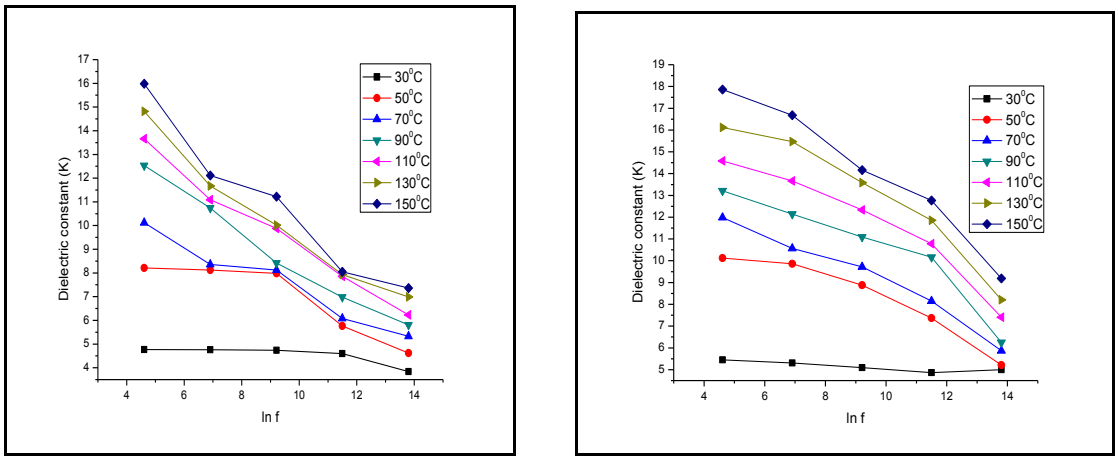


Figure 4.30: Frequency dependence of dielectric constant for treated and untreated composite.

Figure 4.31 presents the dielectric constant of treated coir dust composites as a function of frequency at different testing temperatures. From the figures it is observed that the nature of the plots for all NaOH, KOH and HCl treated samples are similar. Dielectric constant of the composites is decreased with increasing frequency at constant temperature, and increased with increasing temperature at constant frequency. Low frequency and high temperature have more prominent effect on the dielectric constant. Decreasing nature of the K value with increasing frequency is due to the dielectric relaxation which is the cause of anamalous dispersion. At higher frequencies the orientation of polar molecules along the direction of the applied electric field is disturbed.

(a) (b)



(c)

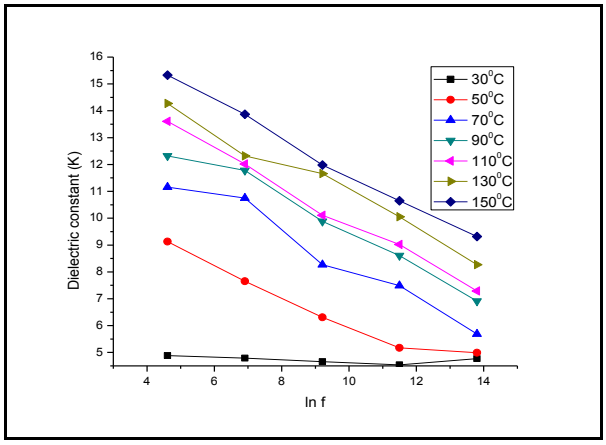


Figure 4.31: Frequency dependence of k-value at different temperatures for (a) NaOH, (b) KOH, and (c) HCl treated composite.

Figure 4.32 presents the variation of the dielectric constant with temperature for treated and untreated coir dust composites and Figure 4.33 represents the temperature dependence of the K-value at different frequencies for treated samples. From the figures it is observed that, with increasing temperature the value of K is increasing for all treated and untreated samples. This is due to the greater freedom of movement of dipole molecular chains. With increasing temperature the polarization increases and hence the dielectric constant is also increased.

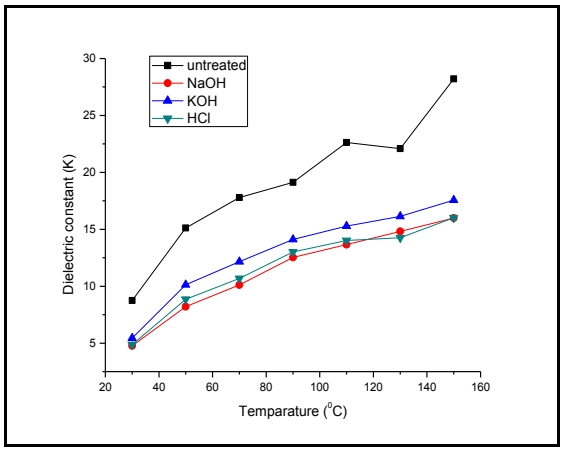
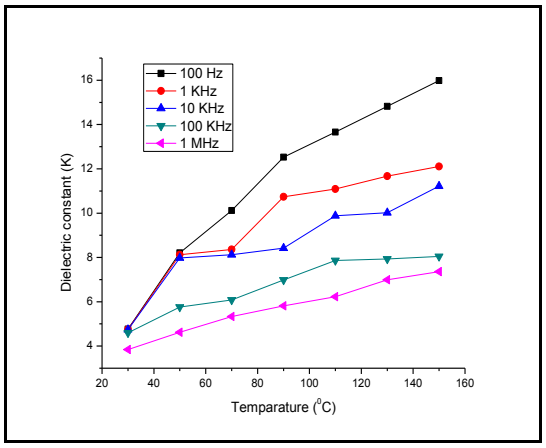
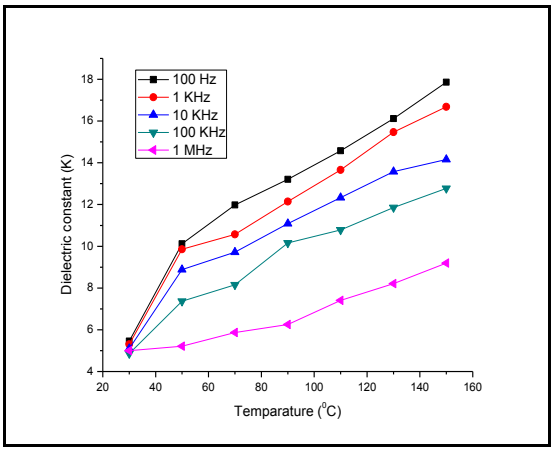


Figure 4.32: Temperature dependence of dielectric constant for treated and untreated composite.

(a) (b)





(c)

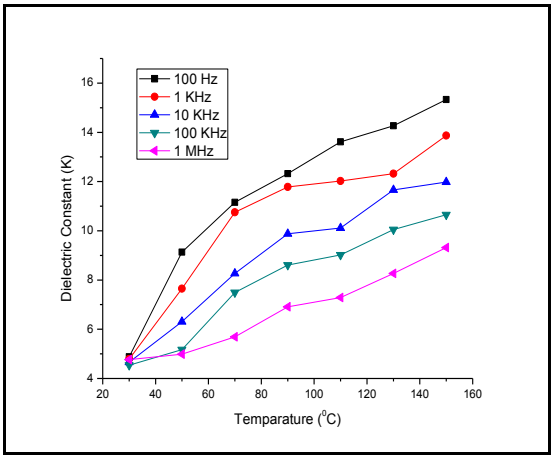


Figure 4.33: Temperature dependence of k-value at different frequencies for (a) NaOH, (b) KOH, and (c) HCl treated composite.

Dielectric loss for treated and untreated composites was presented in Figure 4.34. From the figure it is observed that the dielectric loss of the treated samples is decreased; this is due to the increment in the density of the composite, causing decrement in the charge storage inside the voids.

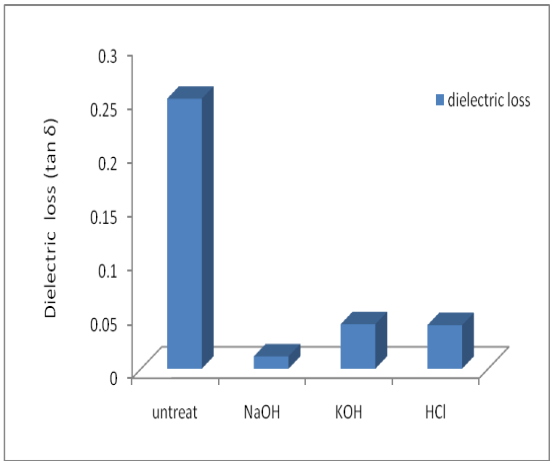


Figure 4.34: Variation of the dielectric loss of treated and untreated coir dust filled polymer composite.

Figure 4.35 presents the frequency dependence of dielectric loss for treated and untreated samples and the Figure 4.36 represents the dielectric loss of treated samples as a function of frequency at different temperatures. It is observed that the loss factor has decreased with increasing frequency at constant temperature. The decrement in the loss factor for high temperature and at low frequency is more prominent which is the usual behavior of most materials.

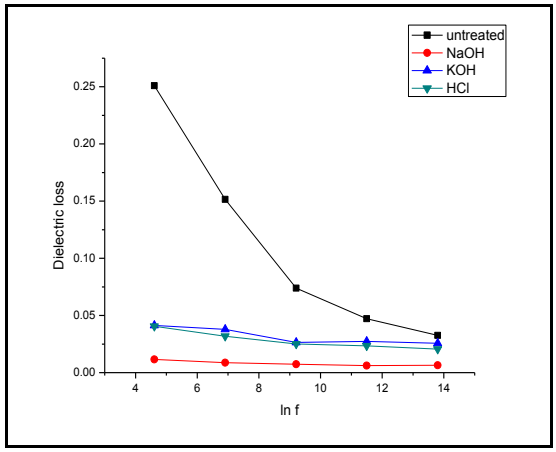
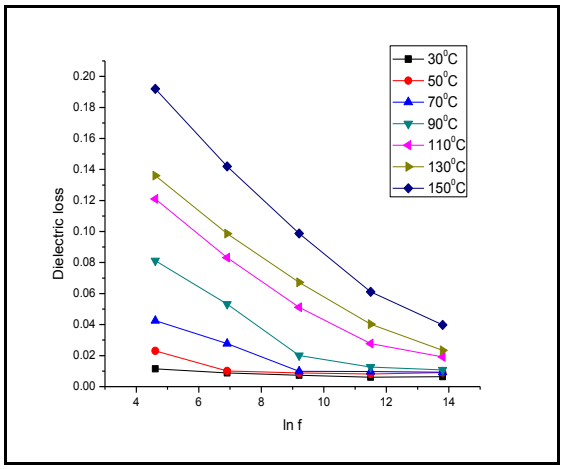
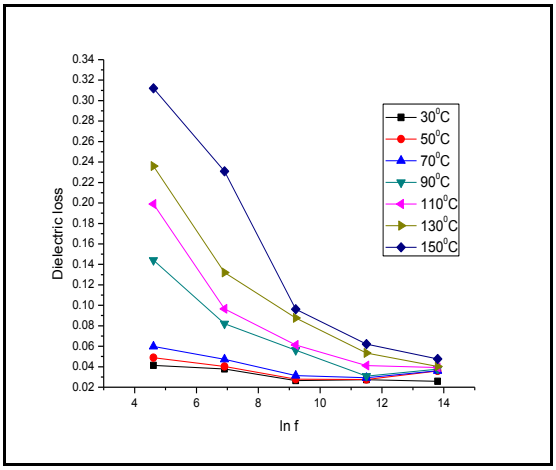


Figure 4.35: Frequency dependence of dielectric loss for treated and untreated composite.

(a)



(b)



(c)

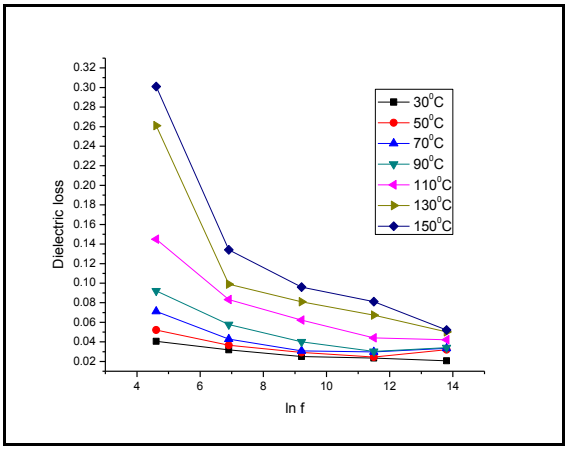


Figure 4.36: Frequency dependence of dielectric loss at different temperatures for (a) NaOH, (b) KOH, and (c) HCl treated composite.

Variation of the dielectric loss with temperature for treated and untreated composites are shown in the Figure 4.37, and the Figure 4.38, indicates the temperature dependence of the loss factor at different frequencies. The nature of the plots for treated and untreated samples is same. From the figures it is observed that, dielectric loss increases sharply with increasing temperature at lower frequencies; where as at higher frequencies the increment in the dielectric loss is negligible.

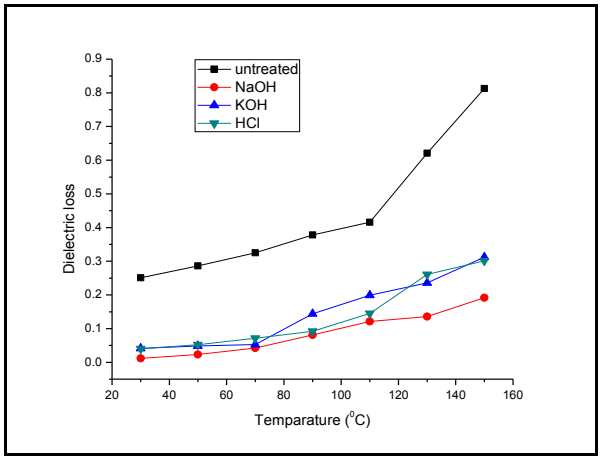
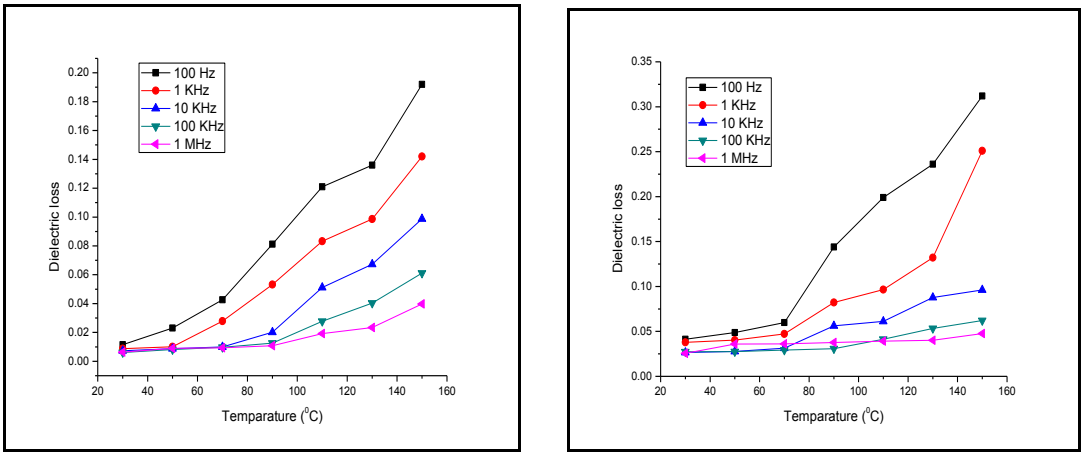


Figure 4.37: Temperature dependence of dielectric loss for treated and untreated composite.

(a) (b)



(c)

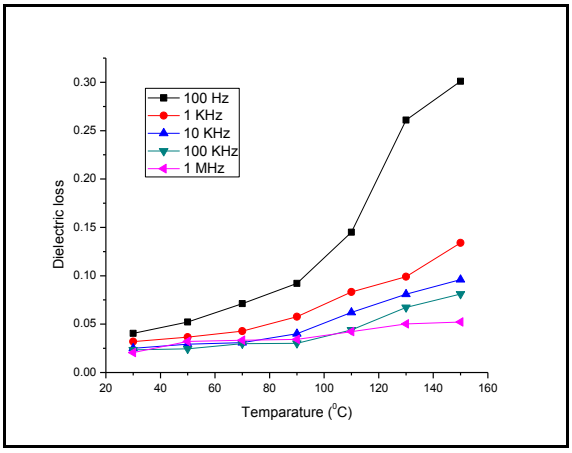


Figure 4.38: Temperature dependence of dielectric loss at different frequencies for (a) NaOH, (b) KOH, and (c) HCl treated composite.

Figure 4.39 presents the frequency dependence of A.C. conductivity and the A.C. resistivity for untreated treated coir dust composites. From the figure it is observed that the conductivity of the material is increased with increasing frequency at room temperature. It is also observed that, at middle of the frequency range the change in the A.C conductivity of NaOH treated sample is high. The resistivity of the material is decreased with increasing frequency at room temperature.

(a) (b)

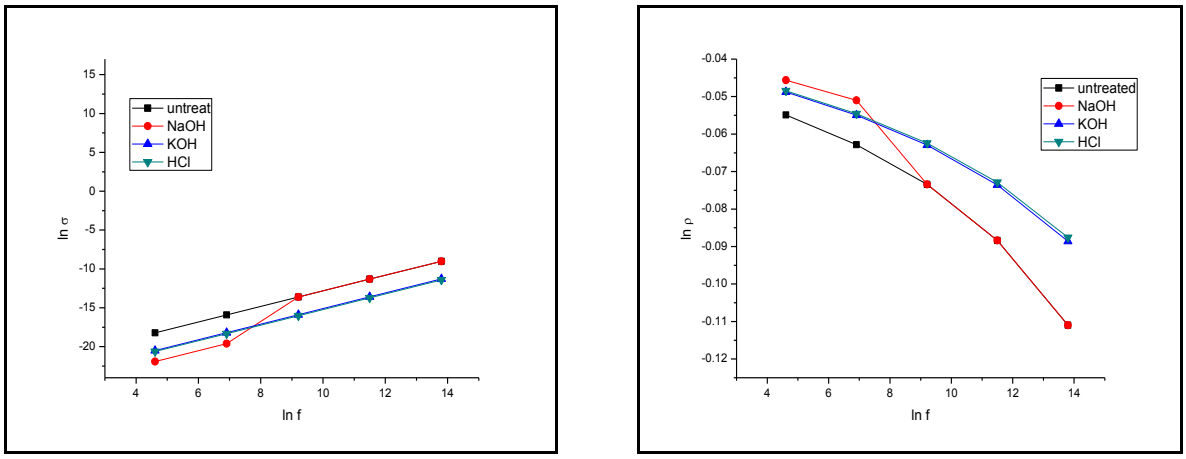


Figure 4.39: Frequency dependence of (a) conductivity, and (b) resistivity.

Chapter 5

CONCLUSIONS

- Conclusions
- Scope for Future Work

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

- The physico-mechanical properties like void fraction, density, flexural strength, hardness of the Bio-Waste coir dust reinforced polymer composites have been studied. The density of the new material decreases with increase of coir dust content. This is due to presents of high air content in the reinforcement. The volume fraction of voids has increased with the incorporation of coir dust in epoxy resin.

- Flexural strength of the composite has decreased with increasing coir dust content in epoxy resin, due to increment in the void fraction.

- Hardness of the composites has also decreased with increasing reinforcement amount, because of the softness of the coir dust as compared to the matrix material.

- Dielectric properties(viz. relative permittivity and loss factor), A.C conductivity, and A.C resistivity of pure epoxy resin and coir dust composites have been studied in the frequency range 100Hz-1MHz ,and in the temperature range 30-150°C .The experimental results indicate that the dielectric constant (vary 6.29-11.84 with wt% of coir dust)and dielectric loss factor(vary 0.00934-0.34512 with wt% of coir dust) are decreases with increasing frequency; due to the orientation polarization and increases with increasing temperature due to greater movement of polar molecular dipole. The A.C conductivity has increased and A.C resistivity is decreased with increasing frequency at room temperature. Maximum variation of conductivity and resistivity with frequency is observed at 40 wt% coir dust addition.

- These coir dust reinforced composites can be useful in the electronics industry for its dielectric and insulating properties in the use of capacitors, microelectronic components (such as transistors and ICs), and safe insulators for low to moderate voltages (hundreds of volts).

- Based on the wear studies carried out on coir dust filled epoxy composites in abrasive wear mode, it is found that the incorporation of coir dust fiber into epoxy can significantly reduce SWR of neat epoxy. The SWR found to be more sensitive to normal load and attains a steady state with increasing sliding distance.

- Erosion wear behaviour of bio-waste coir dust reinforced Polymer composites have been studied by varying amount of coir dust, impingement angle, and impact velocities. From the experiments it is found that the erosion wear resistance has increased with increasing volume fraction of the coir dust, because of the softness of coir dust compare with the matrix material, brittle failure mode of the coir dust composite has been evaluated since composite has exhibited maximum erosion rate at normal incidence and the possible wear mechanisms(the microcracking, microcutting, damage and pulverization) initiated at fiber-matrix interfacs. These low strength coir dust reinforced composites can be useful as coatings on crub slurry carrying pipes where erosion and abrsion is the measure factor for failure the strength of the coatings material.

- The coir dust was treated in different environmental conditions. It is found that, the dielectric constant of treated coir dust composite is lower than that of the untreated coir dust composite. As a whole it can be concluded that, the coir dust reinforced polymer composite, improves the dielectrical behavior by (~15-46%), and the tribological behaviour by (~15-40 %) than that of the epoxy matrix material. A low cost composite could be processed and pollution caused by the coir dust can be prohibited.

5.2 Scope for future work

The present work opens up a wide area for future investigators to explore many aspects of coir dust reinforced polymer composites.They are:

- The work should be extended to study other properties composites such as dielectric strength,thermal conductivity, and chemical resistance.
- The usage of different types of environ mental treatment with different time intervals can be studied for bio wastes based thermoplastic composites.
- Other polymer matrix can be tried for the fabrication of coir dust reinforced composites.
- Sliding wear behavior under different operating conditions can be investigated to identify suitable application areas.

Referencess

REFERENCES

1. Hull D. and Clyne, T.W.. An Introduction to composite materials, 2nd ed., Cambridge University, Press, Cambridge, 1996,Pg.1-3.

2. Maldas D. and Koota B.V. "Current trends in the utilization of cellulosic materials in the polymer industry. Trends in the utilization of cellulosic materials in the polymer industry". Trends Polym Sci.1993; 1(6):174-178.

3. Oksman K. "Mechanical properties of natural fiber mat reinforced thermoplastic". Appl Compos Mater. 2000; 7:403-414.

4. Wambua P., Ivens J. and Verpoest I."Natural fibers: can they replace glass in fiber reinforced plastics?" Compos Sci Technol. 2003; 63:1259-64.

5. Bledzki A.K. and Gassan J. "Composites reinforced with cellulose based fibers". Prog Polym Sci. 1999; 24(2):221-74.

6. Saira Taz, Ali Munawar M and Shafiullah Khan."Natural fiber reinforced polymer composites".Pro.Pakistan Acad.Sci.2007; 44(2):129-144.

7.Herrera-Franco,P.J. and Valadez-Gonzalez,A."A study of the mechanical properties of short natural fiber reinforced composites".Comps,Part B: Engng.2005;36:597-608.

8.Lundin,T., Carmer,S.M,Falk,R.H. and Felton,C."Accelerated weathering of natural fiber – filler polyethylene composites".J Mater Civil Eng.2004;16:547-55.

9.Foulk,J.A.,Chao,W.Y.,Akin,D.E.,Dodd,R.B, and Layton,P.A."Enzyme-retted flax fiber and recycled polyethylene composites". J Polym Environ.2004;12:165-71.

10. Tajvidi,M."Static and dynamic mechanical properties of a kenaf fiber –wood flour/polypropylene hybrid composite".J Appl Polym Sci.2005;98:665-72.

11.Cabral H,Cisneros M,Kenny J.M.,Vazquez A and Bernal C.R."Stracture properties relationship of short jute fiber –reinforced polypropylene composites". J Compos Mater.2005;39:51-65

12.Li H.J., and Sain M.M. "High stiffness natural fiber reinforced hybrid polypropylene composites". Polym-Plast Technol Engng .2003;42:853-62.

13. Guffey V.O. and Sabbagh A.B."PV/wood-flour composites compotibilized with chlorinated polyethylene". J Vinyl Addit Tech .2002;8:259-63.

14. Ayora M.,Rios R ,Quijano J and Marquez A. "Evaluation by torque –rheometer of suspensions of semi-rigid and flexible natural fibers in matrix of poly vinyl chloride", Polym CCompos.1997;18:549-60.

15. Mishra S, and Naik J.B. "Effect of treatment of maleic anhydrid on mechanical properties of natural fiber: polystyrene composites". Polym-plastics Tech Eng.2005;44:663-75.

16.Shibata M,Ozawa K, Teramoto N,Yosomiya R. And Takeishi H."Biocomposites made from short abaca fiber and biodegradable polyesters'.Macromol Mater Eng.2003;288:35-43.

17.Wong S, Shanks R.A. and Hodzic H "Mechanical behavior and facture toughness of poly (L-latice acid) –natural fiber composites modified with hyperbranched polymers".Macromol Mater Eng.2004;289:447-56.

18. Nadiya Bihary Nayak, S.C.Mishra and alok Satapathy "Investigation on Bio-waste Reinforced Epoxy Composites" Journal of Reinforced Plastics and Composites; Online First, published on February 25, 2009 as doi: 10.1177/0731684408100740.

19. Hull, D. and Clyne, T.W. 1996. An introduction to composite materials. Cambridge University Press, Cambridge.

20. Agro-wastes as reinforced fillers in polymer composites. Bristol Colloid Annual Review 2008/2009.Page 25.

21.McMullen P."Fiber/resin composites for aircraft primary structures: a short history, 1936-1984", Composites, 1984; 15(3), 222-30.

22. Mohanty A.K., Khan M.A. and Hinrichsen G."Surface modification of jute and its influence on performance of biodegradable jute fabrics polyester amide composites". Composite, Compos Sci. Technol 200; 60-1115-24.

23. Mohanty A.K., Khan M.A. and Hinrichsen G "Influence of chemical surface modification on the properties of biodegradable jute fabrics polyester amide composite".Composites,Part A : Appl.Sci Manufact .2000;31:143-50.

24. Li H.X. Meng Y.Z. Wang S.J.Rajulu A.V. and Tjong S.C. "completely biodegradable composites of polypropylene carbonate and short, lingocellulose fabric hildegradia populifolia". J Polym Sci. Part B 2004; 42; 666-75.

25. Shibata,M. , Takachiyo K ,Ozawa K Yosomiya R and Takeishi H "Biodegradable polyester composites reinforced with short abaca fiber".J Appl Polym Sci.2002;85:129-38.

26. Iannace S, Nicilla G and Nicolasis L"Biocomposites based on sea algae fibers and biodegradable thermoplastics matrices" J Appl Polym Sci 1999; 73:583-92.

27. Kim H.S, Yang H.S. and Kim H.J. Biodegradability and mechanical properties of agro-flour-filled polybuttylene succinate biocomposites .J Appl Polym Sci 2005; 97:1513-21

28. Luo S and Netravali A.N. "Interfacial and mechanical properties of environment friendly green composites made from pineapple fiber and poly resin".J Mater Sci.1999 ;(34):3709-19.

29. Rout J, Mishra M, Tripathy S S Nayak S.K. and Mohanty A.K. "The influence of fiber treatment on the performance of coir-polyester composites". Compos Sci Technol 2001; 61:1303-10.

30. Bisanda, E.T.N. "The effect of alkali treatment on the adhesion characteristics of sisal fibers".Appl Compo Mater 2000; 7:331-9.

31. Gassan J. and Bledzki A.K. "Possibilities for improving the mechanical properties of jute/epoxy composites by alkali treatment of fibers", Compos Sci Technol 1999; 59:1303-9

32. Gross R.A. and Karla B "Biodegradable polymers for environment" Science.2002; 297:803-807.

33. Mohanty A.K. Mishra M. and Drazal L.T. "Sustainable Bio-composites from renewable resources: Opportunities and challenges in the Green Materials world".J Polym Environ 2002; 10:19-26.

34. Drumright R.E. Gruber P.R. and Henton, Dee."Polylactic acid technology".Adv .Mater .2000; 12:1841-1846.

35. Berenberg, B."Natural fibers and resins turn composites green", Compos Technol.13, 2001.

36. Mapleston P. "Automakers see strong promise in natural fiber reinforcements", Modern Plast 1999; 76:73-74.

37. Mohanty A.K. Wibowo A, Misra M and Drazal, L.T."Effect of Process Engineering on the performance of natural fiber reinforced cellulose Acetate bio-composites". Composites, Part A: Appl Sci Manufact 2004; 35:363-370.

38. Mehta G, Mohanty A.K, Mishra M, and Drazal L.T.,"Bio based resin as a toughening agent for bio –composites''. Green Chem.2004; 6:254-258.

39. Bledzki, A.K. and Gassan, J.. Composites reinforced with cellulose based fibers. Prog. Polym. Sci. 1999;24:221-274.

40. Bledzki, A. K., Reinhmane, S. and Gassan, J..Thermoplastics reinforced with wood fi llers. Polym Plast. Technol. Eng. 1998;37:451-468.

41. Marion, P., Andréas, R. and Marie, H.M.. Study of wheat gluten plasticization with fatty acids. Polym.2003; 44:115-122.

42. Mwaikambo, L.Y. and Ansell, M.P.. Hemp fiber reinforced cashew nut shell liquid composites Compos. Sci. Technol. 2003;63:1297-1305.

43. Jiang, L. and Hinrichsen, G.. Flax and cotton fiber reinforced biodegradable polyester amide.Die Angew. Makromol.Chem. 1999;268:13-17.

44. Aziz S. H., Ansell M. P.: The effect of alkalization and fiber alignment on the mechanical and thermal properties of kenaf and hemp bast fibre composites: Part 1 – polyester resin matrix. Composites Science and Technology.2009; 64, 1219–1230 .

45. Amar, K.M., Manjusri, M. and Lawrence, T.D. 2005. Natural Fibers, Biopolymers, and Bio-composites. CRC Press, Tailor & Francis.

46. Geoff Cresswell,"coir dust a proven alternative to peat", Cresswell Horticultural Services, Grose Vale NSW 2753.

47. Wambua, P., Ivens, U. and Verpoest, I.. Natural fi bers: can they replace glass in fiber-reinforced plastics? Compos. Sci. Technol.2003; 63:1259-1264.

48. Rabinowicz, E. (1995). Friction and Wear of Materials. New York, John Wiley and Sons.

49. Williams, J. A. "Wear and wear particles - Some fundamentals." Tribology International .2005;38(10): 863-870.

50. Chattopadhyay, R. (2001). Surface Wear - Analysis, Treatment, and Prevention. OH, USA: ASM-International. ISBN 0-87170-702-0.

51. Chattopadhyay, R. (2004). Advanced Thermally Assisted Surface Engineering Processes. MA, USA: Kluwer Academic Publishers. ISBN 1-4020-7696-7.

52. Jones, M., H., and D. Scott, Eds. (1983). Industrial Tribology: the practical aspects of friction, lubrication, and wear. New York, Elsevier Scientific Publishing Company.

53. Standard Terminology Relating to Wear and Erosion, Annual Book of Standards, Vol 03.02, ASTM, 1987, p 243-250.

54. ASM Handbook Committee (2002). ASM Handbook. Friction, Lubrication and Wear Technology. U.S.A., ASM International. Volume 18.

55. Stachowiak, G. W., and A. W. Batchelor (2005). Engineering Tribology. Burlington, Elsevier Butterworth-Heinemann.

56. Mamata, K. P. "A review on silt erosion in hydro turbines." Renewable & sustainable energy reviews 2008; 12(7): 1974.

57. Sinmazcelik, T. and I. Taskiran."Erosive wear behaviour of polyphenylenesulphide (PPS) composites." Materials in engineering.2007; 28(9): 2471-2477.

58. Pool,K.V ,Dharan,C.K.H, Finnie,I Erosive wear of composite materials, Wear 1986;107 , 1–12.

59. Kulkarani, S.M. Kishore, Influence of matrix modification on the solid particle erosion of glass/epoxy composites, Polym. Polym. Comp. 2001; 9,25–30.

60. Aglan, H.A. ,Chenock Jr. T.A., Erosion damage features of polyimide thermoset composites, SAMPEQ 1993;41–47.

61. Hibbert W.A, . "Helicopter trials over sand and sea", J. Roy. Aeronaut.Soc. 1965,Vol. 69, pp: 769–776.

62. Tilly G. P,. "Erosion caused by airborne particles", Wear, 1969;vol. 14, pp: 63-79.

63. Zahavi J, Nadiv S and Schmitt Jr G. F, . "Indirect damage in Composite materials due to raindrop impact", Wear, 1981;Vol. 72, pp: 305-313.

64. Tilly G. P and Wendy Sage. "The interaction of particle and material behavior in erosion processes", Wear, 1970;Vol. 16, pp: 447-465.

65. Tsiang T.H.Sand erosion of fiber composites: Testing and evaluation in CC. Chamis (Ed.), Test methods for design allowables for fibrous composites, 1989;Vol. 2, American Society for Testing and Materials, (ASTM) STP I003, Philadelphia, pp.55-74.

66. Mathias P-J., Wu W, Goretta K.C, Routbort L.J, Groppi D.P and Karasek K.R. "Solid particle erosion of a graphite-fiber reinforced bismaleimide polymer composite", *Wear*, 1989;Vol. 35, pp: 161-169.

67. Karasek K.R., Goretta K.C., Helberg D.A. and Routbort J.L. "Erosion in Bismaleimide Polymers and Bismaleimide-polymer Composites", Journal of Materials Science Letters, 1992;vol. 11, Issue 16, page: 1143–1144.

68. George J, Sreekala MS, Thomas S.Areview on interface modification and characterization of natural fiber reinforced plastic composites.Polym Engng Sci 2001;1471-85.

69. Varghese S,Kuriakose B,Thomas S.Stress relaxation in short sisalfiber reinforced natural rubber composites.J Appl Polym Sci 1994;53:1051-60.

70.Ahiblad G,Kron A ,Stenberg B.Effect of plasma treatment on mechanical properties of rubber/cellulose fiber composites.Polym Int 1994;33:103-9.

71. Geethamma VG, Joseph R,Thomas S . Short coir fiber-reinforced natural rubber composites: effect of fiber length , orientation and alkali treatment.J Appl Polym Sci 1995;55:583-94.

72. Hornsby PR, Hinrichsen E, Traerdi K .Preparation and properties of polypropylene composites reinforced wtih wheat and flax straw fibers. Part II analysis of composite microstructure and mechanical properties.J Mater Sci 1997;32:1009-15.

73.Mi Y, Chen X ,Guo Q.Bamboo fiber reinforced polypropylene composites: crystalyzation and interfacial morphology . JAppl Polym Sci 1997;64:1267-73.

74.Coutinho FMB, Costa THS ,Carlaho DL.Polypropylene-wood fiber composites:effect of treatment and interfacial morphology .J Appl polym Sci 1997;65:1227-35.

75. Oksman K, Lindberg H, Holmgren A. The nature and location of SEBS-MA compatibilizer in polyethylene-wood fiour composites . J Appl Polym Sci 1998;69:1227-9.

76. Herrera-Franco PJ , Valadez-Gonzalez A. Mechanical properties of continous natural fiber –reinforced polymer composites.composites: part A 2004;35:339-345.

77. Cazaurang-Martinez MN, Herrera-Franco PJ, Gonzalez-chi PI, Aguilar –Vega M. Physical and mechanical properties of henequen fibers .J Appl Polym Sci 1991 ;43:749-56.

78. Kozlowski R , Wladyka –Przybylak M . Flammability and fire resistance of composites reinforced by natural fibers.Polymers for Advanced Technologies ,2008;19(6):446-453.

79. Hager A,Friedrich K,Dzenis YA, Paipetis SA . Studies of erosion wear of advanced polymer composites,in K.Street,B.C.Whistler (Eds),Proceeding of ICCM 10, Wood head Publishing,Cambridge.1995;155-162.

80. Roy M,Viswanathan M,Sundararajan G.The solid particle erosion wear of polymer matrix composites .Wear 1994;171:149-161.

81. Rabinowicz, E. (1995). Friction and Wear of Materials. New York, John Wiley and Sons.

82. Standard Terminology Relating to Wear and Erosion, Annual Book of Standards, Vol 03.02, ASTM, 1987, p 243-250.

83. ASM Handbook Committee . ASM Handbook. Friction, Lubrication and Wear Technology. U.S.A., ASM International. 2002;Volume 18.

84. Friedrich K., Lu Z. and Hager A.M., . "Recent advances in polymer composites tribology", *Wear,1996;* Vol. 190, pp: 139–144.

85. Lancaster J.K., "The effect of carbon fiber reinforcement on friction and wear of polymers", *Br. J. Appl. Phys*., 1968;Vol.1, and pp: 549–559.

86. Lu Z., Friedrich K., Pannhorst W. and Heinz J. "Wear and friction of unidirectional carbon fiber–glass matrix composite against various counterparts", *Wear, 1993;*Vol. 162–164, pp: 1103–1110.

87. Viswnath B., Verma A.P. and Kameswara rao C.V.S.. “Effect of reinforcement on friction and wear of fabric reinforced polymer composites”, *Wear, 1993;*Vol. 167, pp: 93–99.

88. Harsha A.P. and Tewari U.S. “Tribo performance of PAEK composites, Polym Test 21, 2002;pp. 697–709.

89. K.N. Shivakumar, G. Swaminathan and M. Sharpe, “Carbon/vinyl ester composites for enhanced performance in marine applications”, *J Reinf Plast, Compos.2006;* Vol. 25, and pp: 1101–1116.

90. Chand N., Nayak A. and Neogi S. “Three-Body Abrasive Wear of Short Glass Fiber Polyester Composite”, *Wear*, 2000;Vol. 242, and pp: 32–46.

91. Evans D.C. and Lancaster J.K. “The Wear of Polymers, In: Scott, D. (Ed.), Treatise on Materials Science and Technology, New York, USA; Academic Press, 1979;Vol. 13, pp: 85––139.

92. Budinski K.G. “Abrasive Wear Resistance of Polymeric Materials”, *Wear*, 1997;Vol. 203–204, pp: 302–309.

93. Cenna A.A., Doyle J., Page N.W. and Dastoor P. “Wear Mechanisms in Polymer Matrix Composites Abraded by Bulk Solids”, *Wear*, 2000;Vol. 240, pp: 207–214.

94. Cirino M., Pipes R.B. and Friedrich K. “The Abrasive Wear Behavior of Continuous Fiber Polymer Composites”, *J. Mater. Sci.,1987*, Vol. 22, pp: 2481–2492.

95. Cirino M., Friedrich K. and Pipes R.B. “Evaluation of Polymer Composites for Slidingand Abrasive Wear Application”, *Composites*, 1988;Vol. 19, and pp: 383–392.

96. Lhymn C., Tempelmeyer K.E. and Davis P.K.,. “The Abrasive Wear of Short Fiber Composites”, *Composites*, 1985;Vol. 16, and pp: 127–136.

97. Friedrich K., Lu Z. and Scherer R. “Wear and Friction of Composite Materials”, Elsevier, Amsterdam, 1992;pp. 67–85.

98. Bijwe J., Logani C.M. and Tewari U.S. “Influence of Fillers and Fiber Reinforcement on Abrasive Wear Resistance of Some Polymeric Composites”, Proceedings of the International Conference on Wear of Materials, Denver, CO, USA, 1989; pp. 75–92.

99. Bijwe J., Tewari U.S. and Vasudevan P. “Friction and wear studies of short glass fibre reinforced polyetherimide composite”, *Wear*, 1989;Vol. 132, pp: 247-264.

100. Sung N.H. and Suh N.P. “Effect of fiber orientation on friction and wear of fiber reinforced polymeric composites”, *Wear*, 1979;Vol.53, pp: 129–141.

101. Chang H.W. “Wear characteristics of composite: effect of fiber orientation”, *Wear*, 1983,Vol. 85, and pp: 81-91.

102. Jain V.K. “Investigation of the wear mechanism of carbon-fiber reinforced acetyl”. *Wear*, 1983;Vol. 92, pp: 279–292.

103. Suresha, G. Chandramohan, P. Sampathkumaran, S. Seetharamu and S. Vynatheya, . “Friction and wear characteristics of carbon-epoxy and glass-epoxy woven roving fiber composites, *J Reinf Plast Compos*., 2006;Vol. 25, pp: 771–782.

104. Soutis C. “Carbon fiber reinforced plastics in aircraft construction”, *mater, Sci Eng A.*, 2005;Vol. 412, pp: 171–176.

105. Bijwe J., Rattan R. and Fahim M. “Erosive wear of carbon fabric reinforced polyetherimide composites: role of amount of fabric and processing technique”, *Polym Compos.*, 2008;Vol. 29, pp: 337–344.

106. Rekha Rattan and Bijwe J. “Carbon fabric reinforced polyetherimide composites: influence of weave of fabric and processing parameters on performance properties and erosive wear”, *Mater Sci Eng A, 2006;*Vol. 420, pp: 342–350.

107. Hutchings IM. Tribology; friction and wear of engineering materials. In: Arnold E, editor. Division of holder and sought on. London: CRC Press; 1992.

108. Mody P.B., Chou T.W. and Friedrich K. “Effect of testing conditions and Microstructure on the sliding wear of graphite fiber/PEEK matrix composites”, *J Mater Sci, 1988;*Vol. 23, pp: 4319–4330.

109. G.W.Stacowiak, “Wear Materials, Mechanisms and Practices”, Wiley publication ,2006; pp: 1-4.

110. Characterization and failure analysis of plastic, ASM International, 2003; pp: 359-366.

111. Neale MJ, Gee M. Guide to wear problems and testing for industry. New York, USA: William Andrew Publishing; 2001.

112. Vaziri M., Spurr R.T. and Stott, F.H. “An Investigation of the Wear of Polymeric Materials”, *Wear, 1988;*Vol. 122, pp: 329–342.

113. Friedrich K. and Cyftka M. “On The Wear of Reinforced Thermoplastics by Different Abrasive Papers”, *Wear*, 1985;Vol.103, pp: 333–344.

114. Gates G.D. “Two-Body and Three-Body Abrasion: A Critical Discussion”, *Wear*, 1998;Vol. 214, pp: 139–146.

115. Tsukizoe T. and Ohmae N. “Friction and wear of advanced composite materials”, Fibre Science Technology, 1983;Vol. 18, pp: 265.

116. Bahadur S. and Zheng Y. “Mechanical and Tribological Behavior of Polyester Reinforced with. Short Glass Fibers”, Wear, 1990;Vol. 137, pp: 251-266.

117. Bijwe J. and Tewari, U.S. “On the abrasive wear of some polyimides and their composites”, Tribology International, 1991;Vol. 24, pp: 247-253.

118. Chand N. and Fahim M. “Abrasive wear behavior of some FRP composites”, Research and Industry, 1995;Vol. 40, pp: 182-188.

119. Lhymn C., Tempelmeyer K.E., Davis P.K, “The abrasive wear of short fibre composites”, Composites, 1985;Vol. 16, pp: 127-136.

120. Dielectric. Encyclopedia Britannica.

121. "Dielectrics (physics)". Britannica. 2009. pp. 1. Online.

122. Arthur R. von Hippel, Dielectric Materials and Applications, Technology Press of MIT and John Wiley, NY, 1954

123. Kremer F., Schonhals A., Luck W. Broadband Dielectric Spectroscopy– Springer-Verlag, 2002.

124. Ronald J. Gutmann, IEEE Trans. Microwave Theory Tech., 1999;47, 667.

125. Nobuyoshi Awaya, Hiroshi Inokawa, Eiichi Yamamoto, Yukio Okazaki, Masayasu Miyake, Yoshinobu Arita, and Toshio Kobayashi, IEEE Trans. Electron Devices, 1996;43, 1206.

126. The National Technology Roadmap for Semiconductors (Semiconductor Industry Association, San Jose, California, 2001).

127. Golden, J. H. ,Hawker, C. J. and Ho, P. S. Designing Porous Low-k Dielectrics (Semiconductor International, 2001).

128. Aoi, N. Jpn. J. Appl. Phys., Part 1 1997;36,1355.

129. Wu, W. ,Wallace, W. E. Lin, E. K. ,. Lynn, G. W , Glinka, C. J. , Ryan, E. T. and Ho, H. M. J. Appl. Phys., 2000;82,1193.

130. M. H. Jo, H. H. Park, D. J. Kim, S. H. Hyun, S. Y. Choi, and J. T. Paik, J. Appl. Phys., 1997;87, 1299.

131.Denison, . D. R. ,Barbour, J. C. and. Burkart, J. H, J. Vac. Sci. Technol., A14, 1996; 1124.

132. Tada, M,Harada, Y., Hijioka, K., Ohtake, H. T. Takeuchi, S. Saito, T. Onodera, M. Hiroi, N. Furutake, and Y. Hayashi, IEEE International Interconnect Technology Conference, 2002, p. 12.

133. Pillai, P. K. C., Narula G. K. and Tripathi, A. K. , Polym. J., 1984;16, 1984, 575.

134. Tripathi A. K. and Pillai, P. K. C. Proceedings of the 5 th International Symposium on Electrets, Heidelberg (IEEE, New York. 1985).

135. Leyla Aras and Bahattin M. Baysal, J. Polym. Sci. Polym. Phys. Edn., 1984;22,1453.

136. Singh, D. B,Kumar, A,Tayal V. P. and Sanyal, B. Journal of Materials Science, 1988;23, 523.

137. Dale, E.W. and O'Dell, J.L. Wood-polymer composites made with acrylic monomers, isocyanate and maleic anhydride. J. Appl. Polym. Sci. 1999;73:2493-505.

138. Patil, Y.P., Gajre, B., Dusane, D. and Chavas, S. Effect of maleic anhydride treatment on steam and water absorption of wood polymer composites prepared (12): heat straw, cane bagasse, and teakwood sawdust using novella as matrix. J. Appl. Poly. Sci. 2000;77:2963-2967.

139. Bledzki, A.K., Reihmane, S. and Gassan, J. Thermoplastics reinforced with food fi llers: a literature review; Polym. Plast Technol. Eng. 1998;27: 451-468.

140. Mani, P. and Satyanarayan, K.G. Effects of the surface treatments of lignocelluloses fibers on their debonding stress. J. Adh. Sci. Technol. 1990;4:17- 24.

141. Mitra, B.C., Basak, R.K. and Sarkar, M. Studies on jute-reinforced composites, its limitations, and some solution through chemical modify cations of fi bers. J. Appl. Polym. Sci. 1998;67:1093-1100.

142. Samal, R.K. and Ray, M.C. Effect of chemical modifi cation on FTIR-spectra and physicochemical behavior of pineapple bead fi bre. J. Poly. Mater. 1997;14:183-188.

143. Joseph, K., Thomas, S. and Pavithran, C.Effect of chemical treatment on the tensile properties of short sisal fi bre-reinforced polyethylene composites. Polymer 1996;37:5139-5149.

144. Selke, S., Yam, K. and Nieman, K. ANTEC'89. Society of Plastics Engineers, pp. 1813-1815.

145. Dalvag, H., Kalson, C. and Stromvall, H.S. The effi cienty of cellulosic fi llers in common thermoplastics.2. Filling with processing aids and coupling agents. Int. J. Polym. Mater. 1985;11 (1):9-38.

146. Zadorecki, P. and Foldin, P. Surface modify cation of cellulose fi bres. III. Durability of cellulose- polyster composites under environmental aging. J. Appl. Polym. Sci. 1986;31:1966-1970.

147. Maldas, D. and Kokta, B.V. Infl uence of phthalic anhydride as a coupling agent on the mechanical behavior of wood fi ber-polystyrene composites. J. Appl. Polym. Sci. 1990;41:185-194.

148. Razi, P.S., Portier, R. and Raman, A. Studies on polymer-wood interface bonding: effect of coupling agents and surface modifi cation. J. Compos. Mater. 1999;33:1064-1079.

149. Silverstein R. M., Bassler G. C. and Morril T. C., (1991). "Spectrometric Identification of Organic Compounds", 5th edn, John Wiley & Sons, Inc., New York.

150. IBen Amor,H.Rekik,H.Kaddami,M.Raihane,MArous,A.Kallel,Journal of Electrostatics 2009;67 ,717-722.

151. Awan E.H and Shamim A.PK ISSN 0022-2941;CODEN JNSMAC.

152.Manual "Electric Loss Measuring Set TRS-10T",Japan.

153. Ruff A.W and Ives L.K. "Measurement of solid particle velocity in erosive Wear", *Wear*,1975; Volume 35, pp: 195-199.

154. Smyth, C.P Dielectric Behaviour and Structure, New York ,McGraw Hill (1995).

155. Akram, M. Javed A .and Rizvi, T.Z .Turk J.Phys,2005;29,355-365.

156. Frohlic, H. Theory of Dielectrics,Oxford University Press,(Oxford.1956),p.13.

157. Smyth C.P."Dielectric Behaviour and Structure" New York, McGraw Hill(1995).

158. Biagiotti J. et al., A systematic investigation on the influence of the chemical treatment of natural fibers on the properties of their polymer matrix composites, Polym Composite 2004;25 (5), pp. 470–479.

159. W. Liu, A.K. Mohanty, L.T. Drzal, P. Askel and M. Misra, Effects of alkali treatment on the structure, morphology and thermal properties of native grass fibers as reinforcements for Polymer matrix composites, J Mater Sci 2004 ;39 , pp. 1051–1054.

160. Mwaikambo L.Y. and Ansell, M.P. Chemical modification of hemp, sisal, jute, and kapok fibers by alkalization, J Appl Poly Sci 2002;84, pp. 2222–2234.

161. Dotan A.L., Da Silva J.L.G, and Qureshi H.A.A.L. Macro and Micro mechanical behavior of natural fiber composites, Mechanics in Design Conf.,University of Toronto, Canada, 1996;2,pp:823-831.

162 Beal.F. Yousif,Ong B.,Leong,Low K,Ong and Wong K.Jye."The effect of treatment on tribo-performance of CFRP Composites". Recent patents on Materials Science 2009; 2, 67-74.

163. Andrzej K.B., Matra L., Abdullah A., and Januz M. “Biological and electrical resistance of Acetylated Flax Fiber Reinforced polypropylene Composites”, Bioresources, 2009;Vol.4No.1, pp.111-126.

164. Pothan L.A., Simon F., Spange S., and Thomas S.”XPS Studies and Chemically modified Banana Fibers”, Biomacromo; ecules,2006; vol.13.No.7, pp: 892-898.

LIST OF PUBLICATIONS

International Publications:

S.C.Mishra and H.Aireddy. "***Evaluation of Dielectric Behaviour of Bio-Waste Reinforced Polymer Composite***", Journal of Reinforced Plastics and Composites. Vol. 30(2), pp: 134 – 141, 2011.

S.C.Mishra and H.Aireddy. "***Mechanical Properties and Tribological Behaviour of Bio-Waste Reinforced Polymer Composite***", Journal of Polymer Composites ID- PC -11-0063 (communicating).

International conference papers poster/oral presentation:

H.Aireddy and S.C.Mishra, "Studies on dielectric and conductivity properties of bio-waste reinforced polymer composites" MACRO -2010 11th *International Conference on Frontiers of Polymers and Advanced Materials*, Dec.15-17,2010 IIT Delhi.

H.Aireddy and S.C.Mishra, "Processing and Properties of Bio-Waste Reinforced Polymer Composites" ISRS -2010 *International Symposium for Research Scholars on Metallurgy, Materials Science and Engineering*, Dec.20-22, 2010 IIT Chennai.

H.Aireddy and S.C.Mishra, "Studies on Abrasion Wear Behavior of Coir Dust Reinforced Polymer Composites" , APSRT- 2011 *International Conference on Advances in Polymer science and Rubber Technology,* March 3-5,2011 IIT Kharagpur.

H.Aireddy and S.C.Mishra, "Erosive wear behavior of bio waste reinforced polymer composites" , APM- 2011 *International Conference on Advancements in polymeric materials*, held on March 25-27,2011 CIPET Chennai.